STUDIES ON TRIBOLOGICAL BEHAVIOUR AND DIELECTRIC PROPERTIES OF BIO-FIBER REINFORCED COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology

In

Metallurgical and Materials Engineering

By

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NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

CERTIFICATE

This is to certify that the work in this project report entitled "studies on tribological behaviour and dielectric properties of bio-fiber reinforced composites" by JAGABANDHU SINGH and RAJESH KUMAR PRUSTY has been carried out under my supervision in partial fulfillment of the requirements for the degree of Bachelor of Technology in Metallurgical and Materials engineering, National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, this work has not been submitted to any other university/institute for the award of any degree or diploma.

Place:

Dr. Subash Chandra Mishra

Date:

Professor

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769008

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Place **Jagabandhu Singh**

Date **Rajesh Kumar Prusty**

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ABSTRACT

Within the last forty years there has been a rapid increase in the production of synthetic composite, those incorporating fibres in various plastics (polymer) dominating the market. These are especially true for materials that are needed for aerospace, under water and transportation application. Yet there is a demand for low density strong stiff abrasion and impact resistant materials which are not corroded and degraded easily.

In recent years the natural or bio fibre composites have attracted substantial importance as a potential structural material. These bio fibre composites are immersing as a viable alternative to glass fibre reinforced composite especially in automotive and building product applications. The combinations of bio-fibres such an kenaf, hemp, flax, jute, henequen, pine apple leaf fibre and sisal with polymer matrices from both renewable and non renewable resources to produce composite materials that are competitive with synthetic composites requires special attention. These composites have attained commercial attraction in automotive industries.

In the present investigation, composite samples with varying filler content (0%, 10%, 20%, 30%, 40%, 50%. 60%, 70%) are made using coir fibres as the reinforcement and polyester as the matrix. Abrasion wear studies are carried out using DUCOM FRICTION AND WEAR MONITOR. on the various coir fibre (10%,20%,30%) reinforced polyester composite have been Tests are performed varying the applied load, velocity and at abrasive particle sizes. It has been found that wear rate reduces with increase in the reinforcement content. Because, as the reinforcement content increases the material loss takes place in all directions. Also it is found that wear rate increases with increasing velocity and increasing load. The wear rate increases with bigger size of abrasive particles. Further, the examination of the worn surfaces of the composites by scanning electron microscopy(SEM) showed that the cracks were spreading in all direction at higher vol% of reinforcement (i.e 30%), also the micro grooves formed are a result of micro-ploughing.

The dielectric behavior of the coir fibre reinforced polyester composite is measured using HP-4192A LF Impedance Analyser, connected with a data acquisition system. It is found that, with increase in the amount of reinforcement, there is a decrease in the dielectric loss. With increase in the reinforcement content the dielectric constant shows a higher value than the pure polyester sample. Change in frequency shows a stabilizing trend on the dielectric constant. However with the increase in temperature the dielectric constant of the composite shows a slightly increasing trend.

CHAPTER 1
INTRODUTION

1.1 BACKGROUND

Many of our modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics, and polymeric materials. This is especially true for materials that are needed for aerospace, underwater, and transportation applications. For example, aircraft engineers are increasingly searching for structural materials that have low densities, are strong, stiff, and abrasion and impact resistant, and are not easily corroded. This is a rather formidable combination of characteristics. Frequently, strong materials are relatively dense; also, increasing the strength or stiffness generally results in a decrease in impact strength.

Material property combinations and ranges have been, and are yet being, extended by the development of composite materials. Generally speaking, a composite is considered to be any multiphase material that exhibits a significant proportion of the properties of both constituent phases such that a better combination of properties is realized. According to this principle of combined action, better property combinations are fashioned by the judicious combination of two or more distinct materials. Property trade-offs are also made for many composites [1].

Within the last forty years there has been a rapid increase in the production of synthetic composite, those incorporating fine fibers in various plastics (polymer) dominating the market. Prediction suggests that the demand for composite will continue to increase steadily with metal and ceramic based composites making a more significant contribution [2].

1.2 WHY TO USE COMPOSITES?

The composites industry has begun to recognize that the commercial applications of composites promise to offer much larger business opportunities than the aerospace sector due to the sheer size of transportation industry. Thus the shift of composite applications from aircraft to other commercial uses has become prominent in recent years.

The various reasons for the use of composites are due to

- To increase stiffness, strength and dimensional stability.
- To increase tough and impact strength.
- To increase heat deflection temperature.
- To increase mechanical damping.
- To reduce permeability to gases and liquids.
- To modify electrical properties.
- To reduce cost.
- To decrease thermal expansion.
- To increase chemical wear and corrosion resistance.
- To reduce weight.

- To maintain strength/stiffness at high temperatures while under strain conditions in a corrosive environment.
- To increase secondary uses and recyclability, and to reduce negative impact on the environment.
- To improve design flexibility [3].

1.3 WHAT IS COMPOSITE?

In general, composite is a material system that is made of two or more material in a macroscopic scale. In material science composite has a number of definitions.

The main constituents of composite are matrix and reinforcement. Matrix holds the reinforcement in their respective position and provides toughness to the system. Reinforcement provides stiffness to the composite. As a result the composite has a optimum balance between strength and toughness.

According to Miracle & Donaldson, a composite material is a macroscopic combination of two or more distinct materials, having a recognizable interface between them. Composites are used not only for their structural properties, but also for electrical, thermal, tribological, and environmental applications [4].

Smith says that, a composite is a materials system composed of a suitably arranged mixture or combination of two or more micro or macro constituent with an interface separating them that differ in form and chemical composition and are essentially insoluble in each other [5].

According to callister, a composite is a multiphase material that is artificially made, as opposed to one that occurs or forms naturally. In addition, the constituent phases must be chemically dissimilar and separated by a distinct interface. Thus, most metallic alloys and many ceramics do not fit this definition because their multiple phases are formed as a consequence of natural phenomena [1].

John says that a composite can refer to any multi phase material. However, it is usually restricted to “tailor made’ materials in which two or more phases have been combined to yield properties not provided by constituents alone [6].

According to Jacobs and Kilduff, A composite material is a complex solid material composed of two or more materials that, on a macroscopic scale, form a useful material. The composite is designed to exhibit the best properties or qualities of its constituents or some properties processed by neither [3].

1.4 CLASSIFICATION OF COMPOSITES

Most composite materials developed thus far have been fabricated to improve mechanical properties such as strength, stiffness, toughness, and high temperature performance.

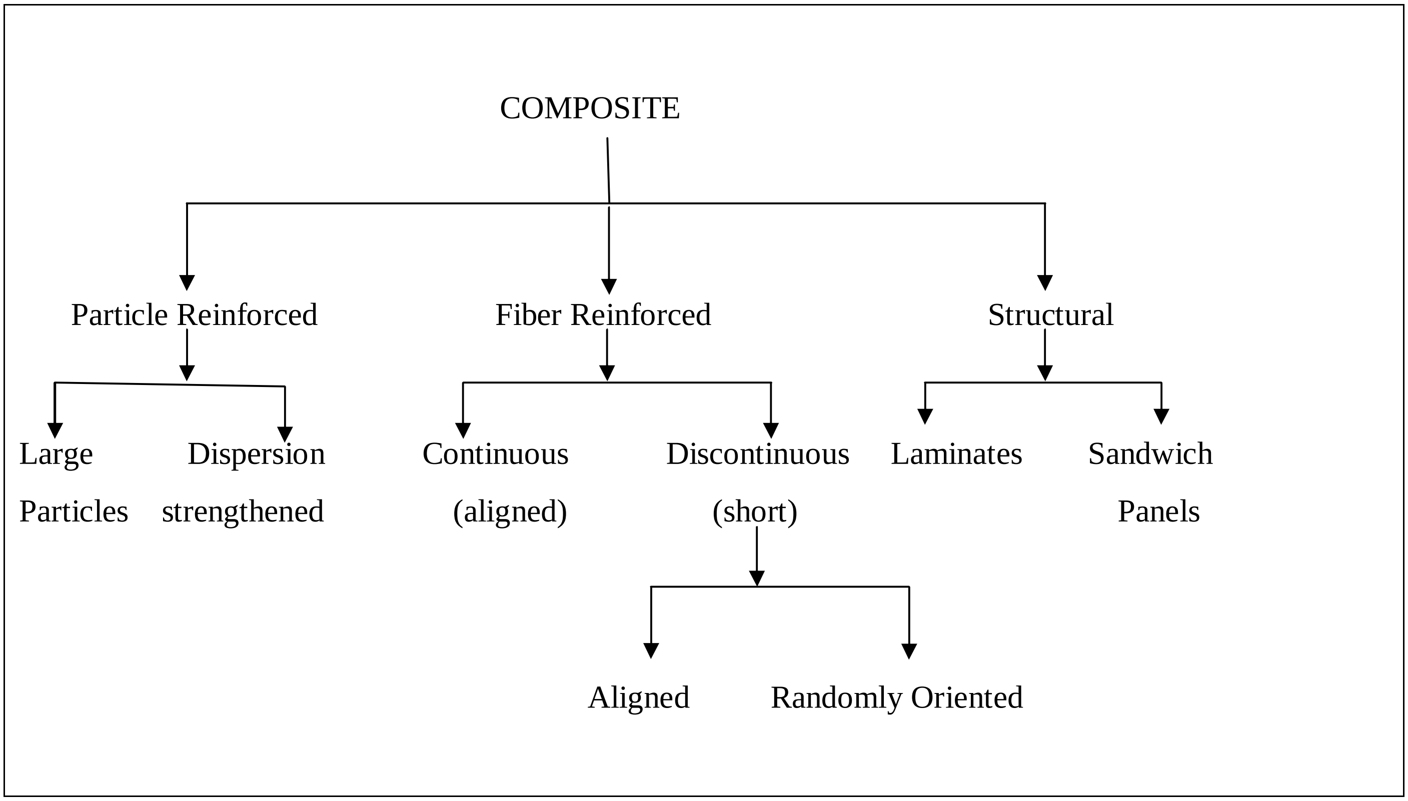

Figure 1.1 Classification Of composites [7]

It is natural to study together the composites that have a common strengthening mechanism. The strengthening mechanism strongly depends on the geometry of the reinforcement. Therefore, it is quite convenient to classify composite materials on the basis of the geometry of a representative unit of reinforcement [8].

Many composite materials are composed of just two phases; one is termed the matrix, which is continuous and surrounds the other phase, often called the dispersed phase. The properties of composites are a function of the properties of the constituent phases, their relative amounts, and the geometry of the dispersed phase. “Dispersed phase geometry” in this context means the shape of the particles and the particle size, distribution, and orientation; these characteristics are represented in Figure 1.2.

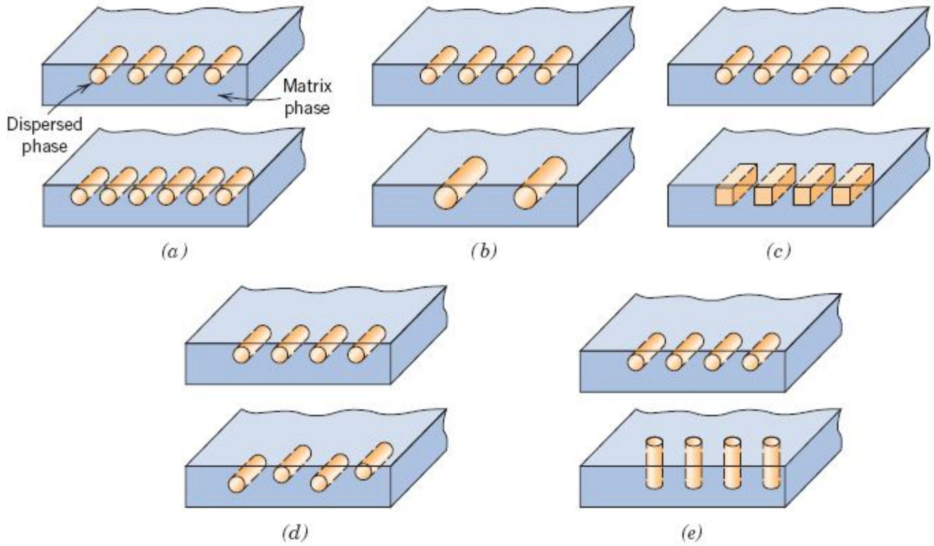

Figure 1.2 Schematic representations of the various geometrical and spatial characteristics of particles of the dispersed phase that may influence the properties of composites: (*a*) concentration, (*b*) size, (*c*) shape, (*d*) distribution, and (*e*) orientation [9].

1.5 CONSTITUENTS OF COMPOSITE

Generally a composite has 2 types of components. The properties of the composite are the net result of its constituents. In general composite consists of a matrix phase which is quite ductile and a reinforcement which provides strength to the composite.

1.5.1 MATRIX & ITS EFFECT

Many materials when they are in a reinforcement form exhibit very good strength property but to achieve these properties the reinforcements should be bonded by a suitable matrix. The matrix separates the fibers from one another in order to prevent abrasion and formation of new surface flaws which acts as a bridge to hold the fibers in place. A good matrix should have good ductility and toughness..

The matrix holds the reinforcements in their appropriate positions and helps in transferring the load to the reinforcement. A matrix has relatively less strength. Generally three types of matrix materials are in use.

- POLYMER MATRIX

A very large number of polymeric materials, both thermosetting and thermoplastic, are used as matrix materials for the composites. Some of the major advantages and limitations of resin matrices are listed below.

Advantages of polymer matrix

- Low densities
- Good corrosion resistance
- Low thermal conductivities
- Low electrical conductivities
- Good formability

Limitations of polymer matrix

- Low transverse strength
- Low operational temperature limits

Maximum operating temperatures for resins as matrices in fiber reinforced composites are listed in table 1.1 to give some idea about their limitation.

Table 1.1 Operating temperatures for common polymer resins [3]

Resin	Maximum temperature (^{0}C)
High performance polyester	150
Epoxies	200
Phenolics	260
Polyimides	300
Polybenimidazole	Above 300

Reinforcement of polymers by strong fibrous network permits fabrication of Polymer Matrix Composites (PMC) characterized by the following properties:

- High tensile strength;
- High stiffness;
- High Fracture Toughness;
- Good abrasion resistance;
- Good puncture resistance;
- Good corrosion resistance;
- Low cost.

Properties of Polymer Matrix Composites are determined by:

- Properties of the fibers;
- Orientation of the fibers;
- Concentration of the fibers;
- Properties of the matrix.

Polymer Matrix Composites (PMC) are used for manufacturing: secondary load-bearing aerospace structures, boat bodies, canoes, kayaks, automotive parts, radio controlled vehicles, sport goods (golf clubs, skis, tennis racquets, fishing rods), bullet-proof vests and other armor parts, brake and clutch linings [10].

- METAL MATRIX

As the name implies, for metal-matrix composites (MMCs) the matrix is a ductile metal. These materials may be utilized at higher service temperatures than their base metal counterparts; furthermore, the reinforcement may improve specific stiffness, specific strength, abrasion resistance, creep resistance, thermal conductivity, and dimensional stability. Some of the advantages of these materials over the polymer-matrix composites include higher operating temperatures, nonflammability, and greater resistance to degradation by organic fluids. Metal-matrix composites are much more expensive than PMCs, and, therefore, their (MMC) use is somewhat restricted [1].

- CERAMIC MATRIX

Ceramic materials are inherently resilient to oxidation and deterioration at elevated temperatures; were it not for their disposition to brittle fracture, some of these materials would be ideal candidates for use in high-temperature and severe-stress applications, specifically for components in automobile and aircraft gas turbine engines [1].

1.5.2 REINFORCEMENT & ITS EFFECT

Reinforcement is introduced in the matrix in an ambition to increase the various mechanical properties. The properties of the composite not only depend on the type of material but also on the size, shape and distribution. Majority of the applied load on the composite is carried by the reinforcement.

- TYPES OF REINFORCEMENT

On the basis of diameter and character, fibers are grouped into three different classifications: whiskers, fibers, and wires.

Whiskers are very thin single crystals that have extremely large length-to-diameter ratios. As a consequence of their small size, they have a high degree of crystalline perfection and are virtually flaw free, which accounts for their exceptionally high strengths; they are among the strongest known materials. In spite of these high strengths, whiskers are not utilized extensively as a reinforcement medium because they are extremely expensive. Moreover, it is difficult and often impractical to incorporate whiskers into a matrix. Whisker materials include graphite, silicon carbide, silicon nitride, and aluminium oxide.

Materials that are classified as fibers are either polycrystalline or amorphous and have small diameters; fibrous materials are generally either polymers or ceramics (e.g., the polymer aramids, glass, carbon, boron, aluminium oxide, and silicon carbide).

Fine wires have relatively large diameters; typical materials include steel, molybdenum, and tungsten. Wires are utilized as a radial steel reinforcement in automobile tires, in filament-wound rocket casings, and in wire-wound high-pressure hoses.

- EFFECT OF FIBER LENGTH

The mechanical characteristics of a fiber-reinforced composite depend not only on the properties of the fiber, but also on the degree to which an applied load is transmitted to the fibers by the matrix phase. Important to the extent of this load transmittance is the magnitude of the interfacial bond between the fiber and matrix phases. Under an applied stress, this fiber–matrix bond ceases at the fiber ends, yielding a matrix deformation pattern as shown schematically in Figure 1.3; in other words, there is no load transmittance from the matrix at each fiber extremity.

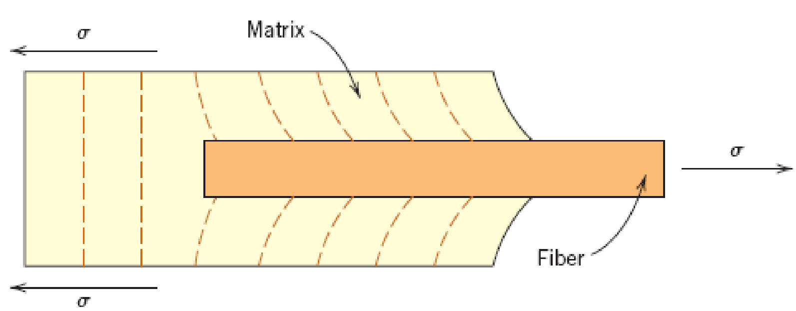

Figure 1.3 The deformation pattern in the matrix surrounding a fiber that is subjected to an applied tensile load.

Some critical fiber length is necessary for effective strengthening and stiffening of the composite material. This critical length is dependent on the fiber diameter *d* and its ultimate (or tensile) strength σ_f and on the fiber–matrix bond strength (or the shear yield strength of the matrix, whichever is smaller) τ_c according to

$lc = \sigma_f d / \tau_c$

- When the fiber length $l < lc$; the reinforcement is particulate in nature.
- When the fiber length $l > lc$ but $l < 15lc$; the reinforcement is a short fiber type.
- When the fiber length $l > 15lc$; the reinforcement is continuous in nature [1].

1.6 APPLICATIONS

This Section highlights selected applications of polymer-matrix composites PMCs), metal-matrix composites (MMCs), and ceramic matrix composites (CMCs).

- ADVANCE POLYMER MATRIX COMPOSITES

Table 1.2 some applications of polymer matrix composites [2]

Industrial Sector	Examples
Aerospace	Wings, fuselage, radomes, antennae, tail-planes, helicopter blades, landing gears, seats, floors, interior panels, fuel tanks, rocket motor cases, nose cones, launch tubes.
Automobile	Body panels, cabs, spoilers, consoles, instrument panels, lamp-housings, bumpers, leaf spring, drive shafts, gears, bearings.
Boats	Hulls, decks, masts, engine, shrouds, interior panels.
Chemical	Pipes, tanks, pressure vessels, hoppers, valves, pumps, impellers,
Domestic	Interior and exterior panels, chairs, tables, baths, shower units, ladders.
Electrical	Panels, housings, switchgear, insulators, connectors.
Leisure	Motor homes, caravans, trailers, golf cubes, racquets, protective helmets, skis, archery bows, surfboards, fishing rods, canoes, pools, diving boards, playground equipment.

- METAL MATRIX COMPOSITES

space shuttle, Hubble telescope, automotive brakes, drive shafts, and cylinder liners. electronic packaging and thermal-management applications.

- CERAMIC MATRIX COMPOSITES

cutting tool inserts and other wear-resistant parts, aerospace and military applications, and various industrial applications, including engines and energy-related applications.

Table 1.3 some applications of ceramic and metal matrix composites [2]

Industrial sector	Application	
	Ceramic matrix	Metal matrix
Aerospace	Afterburners, brakes, heat shields, rocket nozzles	Struts, antennae
Automobile	Brakes	Piston crowns
Manufacturing	Thermal insulation, cutting tools, wire drawing dies	
Electrical		Super conductors, contacts, filaments, electrodes
Medical	Prostheses, fixation plates	

1.7 FIBER REINFORCED POLYMER MATRIX COMPOSITES

Fiber reinforced polymer matrix composite (FRP) is essentially a fiber reinforced in a mtrix generally the fiber used are of high strength and high elastic modulus and serves as the principal load carrying component. So FRPs provide a high strength as well as high toughness values. the FRPs are generally of polymer matrix.

Fiber reinforced polymer (FRP) composites are extensively being used in civil infrastructure. They have tremendous applicability to bridge.

1.8 STANDARD PROPERTIES OF FRP COMPOSITES

The following can be considered as the 'standard' properties typically exhibited by an FRP composites component.

- High strength at low weight
- Ability to tailor properties to meet wide-ranging performance specifications
- Moldings to close dimensional tolerances, with their retention under in- service conditions
- Good impact, compression, fatigue and electrical properties
- Ability to markedly reduce part assembly
- Excellent environmental resistance
- Ability to fabricate massive one-piece moldings
- Proven in-service track record
- Low-to-moderate tooling costs
- Cost-effective manufacturing processes
- Ability to build in, ex-mould, both colour and texture
- Excellent chemical and corrosion resistance
- High ultra-violet radiation stability

1.9 PROPERTIES OF FRP COMPOSITES THAT CAN BE IMPROVED

The following additional properties can readily be provided by reinforcement and/or matrix alteration, chemical addition or other formulation, material, or fabrication alteration.

- Excellent chemical and corrosion resistance
- High ultra-violet radiation stability
- Good-to-excellent fire hardness
- Good structural integrity
- Good thermal insulation
- Respectable abrasion resistance
- Ready bonding to dissimilar materials
- Medium-to-high productivity rates [11]

1.10 CONSTITUENTS OF FRP COMPOSITE

The fibers are usually glass fiber, carbon fiber, aramid fiber, biofibers.
The polymer may be

- Thermosetting -- Epoxy resin, polyester
- Thermoplastics – Amorphous – polysalphones

Additives and modifier ingredients expand the usefulness of polymers, enhance their processability or extend product durability.

1.11 MATERIAL SELECTION

For the preparation of the composite for various testing in this project polyester is chosen as matrix with coir short fiber as reinforcement.

1.11.1 MATRIX MATERIAL (POLYESTER)

TABLE 1.4 Some characteristics and uses of epoxy and polyester thermosets [12]

Thermoset	Some characteristics	Main uses	Limitations
Epoxy	Good electrical properties, Chemical resistance, High strength	Filament winding, Printed Circuit-Board tooling	Require heat curing for maximum performance, Cost
Polyester	Good all-around properties, Ease of fabrication, Low cost, Versatile	Corrugated sheeting, Boats, Piping, Tanks	Ease of degradation

Polyester is a general matrix material which is used in manufacturing of PMCs. Polyester is a thermoset type of polymer. As in the case of epoxides, polyesters have the added advantage over many other thermosets in that they do not require high pressure moulding equipment.

1.11.2 REINFORCEMENT (BIOFIBER)

Natural fibers have recently attracted the attention of scientists and technologists because of the advantages that these fibers provide over conventional reinforcement materials, and the development of natural fiber composites has been a subject of interest for the past few years. These natural fibers are low-cost fibers with low density and high specific properties. These are biodegradable and nonabrasive, unlike other reinforcing fibers. Also, they are readily available and their specific properties are comparable to those of other fibers used for reinforcements. However, certain drawbacks such as incompatibility with the hydrophobic polymer matrix, the tendency to form aggregates during processing, and poor resistance to moisture greatly reduce the potential of natural fibers to be used as reinforcement in polymers [13].

1.12 MECHANICAL PROPERTIES OF BIOFIBER REINFORCED COMPOSITE

TABLE 1.5 Mechanical Properties of Bio Fibers [13]

Fiber	Specific Gr5vity	Tensile Strength, MPa	Modulus, Gpa	Specific Modulus
Jute	1.3	393	55	38
Sisal	1.3	510	28	22
Flax	1.5	377	27	50
Sunhemp	1.07	389	35	32
Pineapple	1.56	170	62	40
Glass fiber-E	2.5	3400	72	28

As can be seen from Table 1.6, the tensile strength of glass fibers is substantially higher than that of bio fibers even though the modulus is of the same order. However, when the specific modulus of bio fibers (modulus/specific gravity) is considered, the bio fibers show values that are comparable to or better than those of glass fibers. These higher specific properties are one of the major advantages of using bio fiber composites for applications wherein the desired properties also include weight reduction.It is generally accepted that the mechanical properties of fiber reinforced polymer composites are controlled by factors such as nature of matrix, fiber-matrix interface, fiber volume or weight fraction, fiber aspect ratio etc [14].

1.13 WEAR

Perhaps the biggest challenge in solving wear problems is that of anticipating the type(s) of wear to which components will be subjected. Material can be removed from a solid surface in only three ways: by melting, by chemical dissolution, or by the physical separation of atoms from the surface. The last method can be accomplished either by the one-time application of a high strain or by cyclic straining at lower magnitudes. Mechanical and chemical processes may operate separately or together, such as abrasion in a corrosive medium [15].

1.14 TYPES OF WEAR

1.14.1 ABRASIVE WEAR

Abrasive wear, as defined by ASTM, is due to hard particles that are forced against and move along a solid surface. Wear, in turn, is defined as damage to a solid surface that generally involves progressive loss of material and is due to relative motion between that surface and a contacting substance or substances. The cost of abrasion is high and has been estimated as ranging from 1 to 4% of the gross national product of an industrialized nation. The effect of abrasion is particularly evident in the industrial areas of agriculture, mining, mineral processing, earth moving, and essentially wherever dirt, rock, and minerals are handled. Examples include plows, ore loading/moving buckets, crushers, and dump truck beds. Abrasion is typically categorized according to types of contact, as well as contact environment. Types of contact include two-body and three-body wear. The former occurs when an abrasive slides along a surface , and the latter, when an abrasive is caught between one surface and another. Two-body systems typically experience from 10 to 1000 times as much loss as three-body systems for a given load and path length of wear.

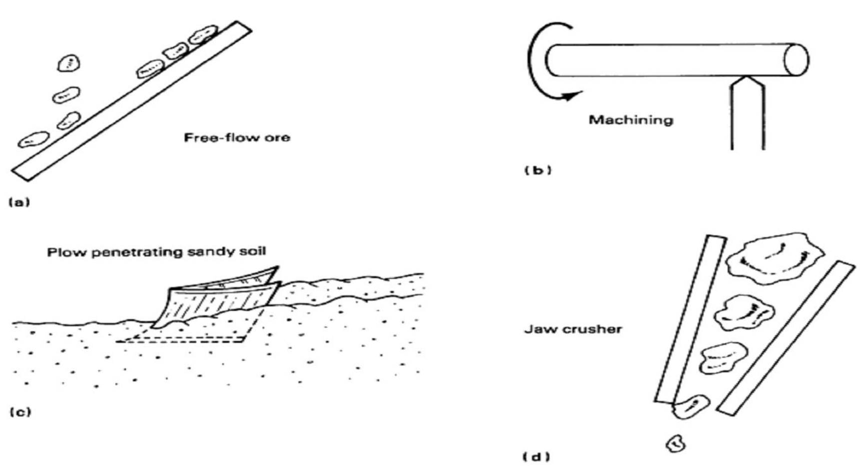

Figure-1.4 Types of contact during abrasive wear. (a) Open two-body. (b) Closed two-body. (c) Open three-body. (d) Closed three-body

- SEVERAL MECHANISMS

Several mechanisms have been proposed to explain how material is removed from a surface during abrasion. These mechanisms include fracture, fatigue, and melting. Because of the complexity of abrasion, no one mechanism completely accounts for all the loss. Figure 1.5 depicts some of the processes that are possible when a single abrasive tip traverses a surface. They include plowing, wedge formation, cutting, micro fatigue, and micro cracking.

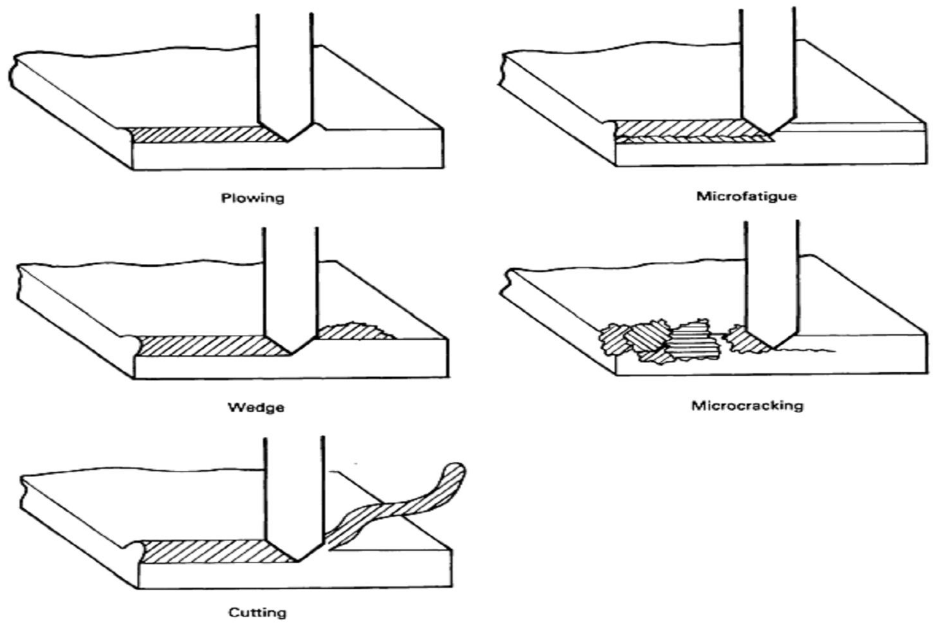

Fig. 1.5 Five processes of abrasive wear

Plowing is the process of displacing material from a groove to the sides. This occurs under light loads and does not result in any real material loss. Damage occurs to the near surface of the material in the form of a build up of dislocations through cold work. If later scratches occur on this cold-worked surface, then the additional work could result in loss through micro fatigue.

When the ratio of shear strength of the contact interface relative to the shear strength of the bulk rises to a high enough level (from 0.5 to 1.0), it has been found that a wedge can develop on the front of an abrasive tip. In this case, the total amount of material displaced from the groove is greater than the material displaced to the sides. This wedge formation is still a fairly mild form of abrasive wear.

The most severe form of wear for ductile material is cutting. During the cutting process, the abrasive tip removes a chip, much like a machine tool does. This results in removed material, but very little displaced material relative to the size of the groove. For a sharp abrasive particle, a critical angle exists, for which there is a transition from plowing to cutting. This angle depends on the material being abraded. Examples of critical angles range from 45° for copper to 85° for aluminium. Abrasion is not dependent on scratches by carefully oriented abrasive grains. Kato and others have analyzed the effect of a rounded tip pushing through a surface.

For ductile materials, the mechanisms of plowing, wedge formation, and cutting have been served. It was found that the degree of penetration was critical to the transition from plowing and wedge formation to cutting. When the degree of penetration, defined as depth of penetration divided by the contact area, exceeded about 0.2, cutting was the predominant mode of wear.

- EFFECT OF ENVIRONMENT ON ABRASIVE WEAR

In addition to the properties of a material, the environment affects wear. As stated earlier, abrasion loss rates are not intrinsic to a material. Environmental factors that effect abrasive loss includes, but are not limited to: the type of abrasive and its characteristics, temperature, speed of contact, unit load of the abrasive on the material, humidity, and corrosive effects, each of which is discussed below.

- ABRASIVE

The hardness of the abrasive particles is important to the rate of abrasion of the subject material. As the hardness of the abrasive exceeds that of the wear material, abrasive wear typically becomes much worse .As the abrasive hardness exceeds the hardness of the material, it is able to penetrate the surface and cut/remove material without having its cutting edges broken or rounded.

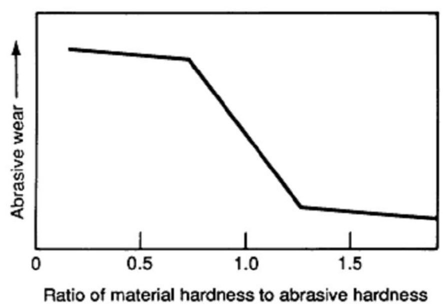

Figure 1.7 Shows the hardness of typical minerals and alloy micro constituents

- TEMPERATURE

It might be expected that abrasive wear would increase as the temperature rises, because the hardness and yield strength decrease. Instead, for aluminium and copper, when the temperature was increased from ambient to 673 K, very little change in the abrasive wear rate was observed. It has been proposed that the reason for this small change is that during abrasion, small areas are adiabatically heated. At higher initial temperatures, the metal flow stress is reduced. This results in less heating in the material during the abrasion process. The end result is that areas around the material that is being removed have a similar temperature, independent of starting temperature, and similar abrasion rates.

- SPEED OF CONTACT

The rate of abrasive wear has been found to slightly increase with increasing speed in the range from 0 to 2.5 m/s (0 to 8.2 ft/s). This increase in wear may be attributable to frictional heating. The effect is small, because all of the abrasion occurs in a near-adiabatic process. This should result in nearly the same peak temperature rise, independent of speed, for the tiny volume of material where the asperities are removing the material.

- LOAD

When load causes fracture of abrasive particle then wear can increase. If the abrasive particle points are rounded, wear will decrease.

- HUMIDITY

The effect of atmospheric humidity on abrasive wear is far from clear, and contrary results exist. Larsen- Basse studied the effect of atmospheric humidity on abrasive wear for a variety of pure metals and steels. When using SiC abrasive, wear usually increased with increasing humidity, up to 65% relative humidity. This increase is attributed to a moisture-assisted fracture of the SiC abrasive particle, which resulted in fresh sharp edges to cut into the surface of the material [16].

1.14.2 SLIDING AND ADHESIVE WEAR

Sliding and Adhesive wear refer to a type of wear generated by the sliding of one solid surface along another surface. Erosion, cavitations, rolling contact, abrasion, oxidative wear, fretting, and corrosion are traditionally excluded from the class of "sliding" wear problems even though some sliding (slip) may occur in some of these types of wear. Apparently, sliding wear is a category of wear that is "left over" when all other types of wear are identified under separate headings.

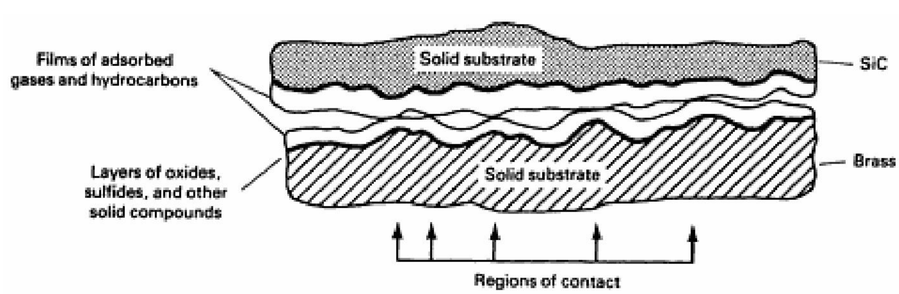

Figure 1.8 Schematic of a bond bridge produced when two solid surfaces are in contact with each other. It should be noted that when two rough surfaces are brought together, actual contact occurs only in a few isolated regions [17].

1.14.3 SOLID PARTICLE EROSION

Solid Particle Erosion (SPE) is the loss of material that results from repeated impact of small, solid particles. In some cases SPE is a useful phenomenon, as in sandblasting and high-speed abrasive water jet cutting, but it is a serious problem in many engineering systems, including steam and jet turbines, pipelines and valves carrying particulate matter, and fluidized bed combustion (FBC) systems [18].

1.14.4 FRETTING WEAR

Fretting is the small-amplitude oscillatory movement that may occur between contacting surfaces, which are usually nominally at rest. One of the immediate consequences of the process in normal atmospheric conditions is the production of oxide debris, hence the term "fretting wear" or "fretting corrosion" is applied to the phenomenon [19].

1.14.5 SURFACE DAMAGE

The type of damage that surfaces display as a result of tribo-contacts is called surface damage.. Surface damage in this context is defined as topographical or microstructural changes, or both, in a surface layer. Surface damage to a tribosystem is most often generated in many consecutive small steps by a number of different micromechanisms that are active in the tribosurface [20].

1.15 DIELECTRIC BEHAVIOUR

A dielectric material is one that is electrically insulating (nonmetallic) and exhibits or may be made to exhibit an electric dipole structure; that is, there is a separation of positive and negative electrically charged entities on a molecular or atomic level. This concept of an electric dipole was introduced. As a result of dipole interactions with electric fields, dielectric materials are utilized in capacitors.

1.15.1 CAPACITANCE

When a voltage is applied across a capacitor, one plate becomes positively charged, the other negatively charged, with the corresponding electric field directed from the positive to the negative. The capacitance *C* is related to the quantity of charge stored on either plate *Q* by

$$C = Q/V$$

where *V* is the voltage applied across the capacitor. The units of capacitance are coulombs per volt, or farads (F). Now, consider a parallel-plate capacitor with a vacuum in the region between the plates as shown in the figure 1.9.The capacitance may be computed from the relationship

$$C = \varepsilon_0 A/l$$

where ‘A’ represents the area of the plates and ‘l’ is the distance between them. The parameter ε_0 called the permittivity of a vacuum, is a universal constant having the value of 8.85×10^{-12} F/m.

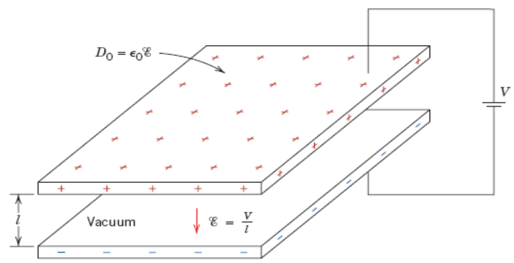

Figure 1.9 A parallel-plate capacitor when a vacuum is present

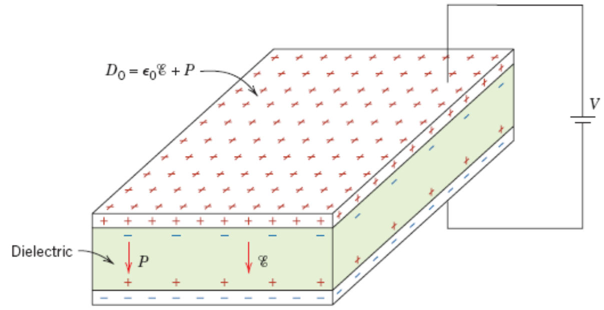

Figure 1.10 A parallel-plate capacitor when a dielectric material is present

If a dielectric material is inserted into the region within the plates as shown in the figure 1.10, then

$C = \varepsilon A/l$

where is the permittivity of this dielectric medium, which will be greater in magnitude than ε_0.The relative permittivity ε_r often called the dielectric constant, is equal to the ratio

$\varepsilon_r = \varepsilon / \varepsilon_0$

which is greater than unity and represents the increase in charge storing capacity by insertion of the dielectric medium between the plates. The dielectric constant is one material property that is of prime consideration for capacitor design. The ε_r values of a number of polymeric dielectric materials are contained in Table1.7.

Table 1.6 Dielectric Constants for Some Polymeric Dielectric Materials[1]

Material	Dielectric Constant, ε_r	
	60 Hz	1 MHz
Phenol-formaldehyde	5.3	4.8
Nylon 6,6	4.0	3.6
Polystyrene	2.6	2.6
Polyethylene	2.3	2.3
Polytetrafluoroethylene	2.1	2.1

The present piece of project work is devoted to fabricate polymer matrix composite using polyester resin as the matrix and coir fiber as the reinforcement and to study the abrasion behaviour and dielectric property of such composites.

CHAPTER 2
LITERATURE SURVEY

2.1 INTRODUCTION

The literature survey is carried out as a part of the thesis work to have an overview of the production processes, properties and wear behaviour of polymer matrix composites. Composite structures have shown universally a savings of at least 20% over metal counterparts and a lower operational and maintenance cost . As the data on the service life of composite structures is becoming available, it can be safely said that they are durable, maintain dimensional integrity, resist fatigue loading and are easily maintainable and repairable. Composites will continue to find new applications, but the large scale growth in the marketplace for these materials will require less costly processing methods and the prospect of recycling will have to be solved.

Kishore, P. Sampathkumaran , S. Seetharamu , P. Thomasb, M. Janardhana [21] have studied the “effect of the type and content of filler in epoxy–glass composite system on the friction and slide wear characteristics”. The comparative performance of glass–epoxy (G–E) composites, having rubber in one instance and graphite of two differing levels in epoxy matrix resin in the other, during sliding in pin-on-disc type set up under varying load and sliding velocities was reported in this investigation. Besides conventional weighing, determination of coefficient of friction (μ) and examination of the worn surface features by scanning electron microscope (SEM) were undertaken to have an overall picture of the tribological behaviour of the filled composites. For increased load and sliding velocity situations, higher wear loss was recorded. In case of rubber-bearing samples, the coefficient of friction values show an increasing trend with a rise in load and a decrease in their values for increase in velocity. The coefficient of friction increases with increase in load for a fixed velocity in higher graphite bearing samples. However, G–E composite having either lower or higher amount of graphite shows, respectively, either a decrease or increase in coefficient of friction with an increase in sliding velocity for a fixed load. Thus, the higher graphite bearing G–E composite records lower coefficient of friction for any combination of load and velocity. These are explained on the basis of frictional drag forces and formation of graphite film on the surface.

The response to tribo situations in G–E polymer composite system is dependent on filler type as well as its amount. Between the two fillers attempted in this work, graphite-bearing ones exhibit lower wear loss, whose value drops down further when the content of the filler in the composite is raised. As regards the coefficient of friction, no one common trend could be observed. This is partly due to the response of the fillers being different. The rubber-bearing samples being elastic offer a different tribo situation compared to graphite, which are prone to basal slip. The amount of this material on the tribo surface also has a bearing on the test parameters recorded. The work points to the need to employ a hybrid filled G–E system, where the differing responses arising from rubber and graphite could well be tapped for applications requiring low wear loss accompanied by moderate values of friction.

Jayashree Bijwe, J. Indumathi, J. John Rajesh and M. Fahim [22] have studied "Friction and wear behaviour of polyetherimide composites in various wear modes". A high performance engineering polymer, polyetherimide (PEI) and its two composites, one containing only short glass fibers (GF) 20% and the other, commercially established bearing material containing 25% GF and three solid lubricants were selected for studying the wear behaviour in four types of wear modes. These included, adhesive (continuous sliding against metal); abrasive (abrading in single pass and multi pass against silicon carbide abrasive paper), and three-body abrasion (abrading against rubber wheel), fretting, and erosive wear modes. A bearing grade material proved to be extremely good in adhesive and fretting wear modes. The same composite, however, proved very poor in abrasive and erosive wear modes. Neat polymer performed best in these two modes. Thus, performance rankings of three materials in adhesive and fretting wear modes were identical while for abrasive and erosive wear modes, exactly the reverse trend was observed. SEM studies proved helpful in understanding the wear mechanism.

Three materials viz. neat PEI (A), PEI+20% short GF (B) and PEI+25% short GF+15% polytetrafluoroethylene (PTFE)+15% (MOS_2 and graphite) (C) were examined for their performance in various wearing modes. These were adhesive, abrasive (three types), erosive and fretting wear. Various operating parameters such as loads, speeds, counter face roughness, etc. were selected as operating conditions. It was concluded that performance of materials very much depended on type of wear mode. Following was the performance ranking observed in these wear modes:

- Adhesive wear mode against mild steel — wear performance was in the order C>>B>>A and the friction behaviour was in the following order C>>A>B.
- Erosive wear mode — wear performance order was A>B>>C.
- Fretting wear mode — wear performance order was C>>B>A and the friction performance order was C>>A≥B.
- Abrasive wear mode, wear performance order was
  - Against SiC paper: single pass condition A>B>>C
  - Against SiC paper: multi pass condition A>B>>C
  - Against rubber wheel: three body abrasion A>B>>C

Thus, composite C, commercially established bearing grade material, performed very well in adhesive and fretting wear modes. Inclusion of GF and three solid lubricants improved the wear performance of neat PEI by the order of three in adhesive wear mode and friction performance by three times. In fretting wear mode, approximately 20 times improvement in wear resistance could be achieved due to reinforcement and solid lubrication while improvement in friction was by two times. Operating parameters such as load, speed, temperature, sliding duration influenced the performance of materials significantly. The same fillers proved detrimental in the case of abrasive and erosive wear performance.

A. A. Cenna, J. Doyle, N. W. Page, A. Beehag and P. Dastoor [23] have studied "Wear mechanisms in polymer matrix composites abraded by bulk solids". An experimental study of the wear of polymer matrix composite materials subjected to abrasion from bulk materials has been conducted. Three examples of vinyl ester resin systems were considered: (a) unreinforced, (b) reinforced with glass fibres, and (c) reinforced with particles of ultra high molecular weight polyethylene (UHWMPE). Soft and hard bulk materials used for abrasion were granular forms of coal and the mineral ignimbrite. The bulk material was presented to the wear surface on a conveyor belt in a novel wear tester. While UHWMPE reinforcement enhanced the wear resistance to both hard and soft abrasives, the situation for fibre reinforcement was more complicated. With coal as the abrasive, it was found that glass fibre reinforcement reduced the wear rate, whereas in the case of the harder ignimbrite, fibre reinforcement increased the wear rate. Microscopy indicated significant differences in the mechanism of wear in each surface/abrasive combination. Wear textures, consistent with both two and three-body wear, were observed with, respectively, soft and hard abrasive particles.

Specimens of three different composite materials, vinyl ester resin, glass fibre reinforced resin, and UHWMPE particle reinforced resin, have been abraded using hard (ignimbrite) and relatively soft (coal) bulk solids. In general terms, lower wear rates were obtained for surfaces abraded by coal than for surfaces abraded by ignimbrite. These lower wear rates, in the case of coal, were a consequence of both lower particle hardness and decreasing particle size during abrasion. The abrasion resistance of reinforced composite materials is a consequence of the micro-mechanics that occur during abrasive wear, which in turn, are strongly dependent upon the hardness of the wear media. Both two-body and three-body wear patterns are possible with bulk solids sliding across polymer matrix composites. The transition between two-body and three-body wear depends on the hardness of the abrasive particles. In this work, hard particles lead to spall type failure consistent with micro-cracking of the surface caused by fatigue. In contrast, two-body wear patterns involving cutting and ploughing were observed with soft particles. Micro-cracking of the matrix caused by surface fatigue is the dominant mechanism of abrasive wear of polymer matrix composites caused by bulk solids. In the two-body wear process, this micro-cracking occurs predominantly as a result of ploughing. In the three-body case, this micro-cracking is the result of cyclic point loading as abrasive particles roll. In the case of both mechanisms, this surface fatigue failure can be inhibited by the use of a suitable reinforcement. Indeed, it is the nature of the reinforcement, rather than the matrix material, which dominates the wear rate. For fibre reinforced surfaces, the brittle fibres are highly vulnerable to fracture by harder abrasive particles, even though these materials offer protection against softer abrasives. Increasing the toughness of the reinforcing materials (as is the case for UHMWPE particles) increases the wear resistance of the materials to both soft and hard abrasives. Thus, the selection of an appropriate reinforcing material for enhancing the abrasion resistance of a composite surface is strongly governed by the material properties of both the abrasive particle and the reinforcement.

Jiang, Gyurova, Schlarb, Friedrich and Zhang [24] studied “friction and wear behavior of polyphenylene sulfide composites reinforced by short carbon fibers and sub-micro TiO_2 particles”. Polyphenylene sulfide (PPS) composites filled with short carbon fibers (SCFs) (up to 15 vol.%) and sub-micro-scale TiO_2 particles (up to 7 vol.%) were prepared by extrusion and subsequently injection-moulding. Based on the results of sliding wear tests, the tribological behaviour of these materials was investigated using an artificial neural network (ANN) approach. A synergistic effect of the incorporated short carbon fibers and sub-micro TiO_2 particles is reported. The lowest specific wear rate was obtained for the composition of PPS with 15 vol.% SCF and 5 vol.% TiO_2. A more optimal composition of PPS with 15 vol.% SCF and 6 vol.% TiO_2 was estimated according to ANN prediction. The scanning electron microscopy (SEM) observation revealed that this hybrid reinforcement could be interpreted in terms of a positive rolling effect of the particles between the two sliding surfaces, which protected the short carbon fibers from being pulled-out of the PPS matrix.

A synergistic effect of the two fillers on improving the wear resistance was reported. The lowest specific wear rate of approximately 4.0×10^{-7} mm^3/Nm was found for PPS with 15 vol.% SCF and 5 vol.% TiO_2. A more optimal composition of PPS with 15 vol.% SCF and 6 vol.% TiO_2 was estimated by ANN prediction.

The possible interaction of short carbon fibers and TiO_2 could be interpreted in terms of a positive rolling action of sub-micro TiO_2 particles, which protected the short carbon fibers from being pulled-out from the matrix by the counterpart asperities and finally resulted in an enhanced wear resistance of the composites.

Sliding speed and applied pressure have their respective influence on the wear of PPS with 15 vol.% SCF and 5 vol.% TiO_2. Under higher *pv*-conditions, the increase in sliding speed results in a relative milder increase of depth wear rate in comparison to that in applied pressure. The phenomenon indicates that a combination of appropriately high sliding speed and applied pressure can augment the hybrid reinforcement effect of the two fillers and develop a compact and smooth transfer film, and consequently reduce the severity of wear.

Tayeb[25] studied “Abrasive wear performance of untreated SCF reinforced polymer composite”. This work aims to present a study on abrasive wear behaviour of polymer reinforced with natural fibre. Specifically, untreated sugarcane fibre (SCF) was used in two forms to reinforce polyester (SCRP). Chopped SCFs with different lengths (1, 5, 10 mm) randomly dispersed (C-SCRP) and continuously unidirectional fibres (U-SCRP) with two different orientations were prepared using hand-lay up and closed mould techniques. Despite the good adhesion between fibre and matrix, results of mechanical tests showed poor tensile strength of SCRP composite. This was attributed to the weak site inside the fibre itself which could not bear the stress transfer from matrix via the fibre. Experimental results of abrasive wear tests revealed that wear of SCRP composite was sensitive to variations of load, fibre length and fibre orientation and less sensitive to sliding velocity. In C-SCRP composite, the lowest wear resistance was observed for composite with 1 mm fibre length as the fibres had no support and removed easily with minimum resistance to the action of abrasive particles followed by 10 and 5 mm fibre length. Meanwhile, C-SCRP composite with 5 mm fibre length offered the highest resistance to material removal compared to the other fibre length used. In U-SCRP composite, the anti-parallel-orientation (APO) exhibited better wear performance compared to the parallel-orientation (PO) one. The predominant wear mechanisms in the case of C-SCRP composite were plastic deformation, micro-cutting, pitting in the matrix, and fibre removal. In the case of U-SCRP composite in (PO) wear mechanisms were micro-cutting, ploughing, fragmentation of wear debris in the matrix and excessive deterioration of fibre surface followed by delamination, while in (APO) the wear mechanisms were micro-cutting in the resin matrix and tearing the fibre transversely at their ends.

The mechanical and abrasive wear behaviours of sugarcane fibre/polyester SCRP composite were studied in this work. The abrasive test was performed against SiC abrasive paper of grade 400 as an abraded counter face using pin-on-disc machine. The influence of reinforcement with chopped SCFs of lengths (1, 5, 10 mm) randomly dispersed in the composite and unidirectional fibre mat orientations (parallel PO and anti-parallel APO) reinforced polyester have been studied. The following conclusion may be drawn:

• The abrasion behaviour of SCRP composites were affected by the length of the chopped SCFs and by the relative orientation of the SCFs with respect to rubbing surface. In addition, abrasion properties of C-SCRP and U-SCRP composites were substantially sensitive to the variation of normal load (increases with increasing load) and less sensitive to variation of sliding velocity.

• The C-SCRP composite with 1 mm fibre length gave the poorest wear compared to the composite with 5 and 10 mm fibre length suggesting that 1 mm fibre length did not receive any support from the matrix during the rubbing process to resist the tangential abrasive forces while longer fibre offers higher resistance due to better embedded length in the matrix.

• For U-SCRP composite, specimens with APO fibres gave higher abrasion resistance than those with the PO tested under identical conditions.

• Examination of SEM micrographs of the worn surfaces revealed five to six different types of wear mechanisms that took place during the abrasion tests of C-SCRP and U-SCRP composites. In C-SCRP composite, a severe plastic deformation, micro-cutting in the matrix, and fibre removal were responsible for material removal. Also under high load and speed conditions, a damage of pitting type very similar to fatigue pitting was evident. In U-SCRP composite (PO), the wear mechanisms were micro-cutting, ploughing, and fragmentation of wear debris in the matrix, excessive deterioration of fibre surface by repeated shearing process followed by delamination of the fibre. In U-SCRP composite (APO), the removal of material was due to micro-cutting in the resin matrix and tearing the fibre transversely at their ends.

• Finally, the results obtained here, as stated earlier, showed that the fabricated SCRP composite has a lot potential as a low cost polymeric composite material for tribological applications. However, one may say that as a preliminary study, the present work has revealed many interested areas for further investigation, namely, effect of chemical treatment of fibre surfaces, fibre length, volume fracture, and different architectures of reinforcement etc.

Aurrekoetxea, Sarrionandia and Gómez [26] studied "Effects of microstructure on wear behaviour of wood reinforced polypropylene composite". Friction coefficient, wear rate and wear micromechanism of wood reinforced polypropylene (WPC), pine wood and polypropylene (PP) have been compared. WPC and wood present very similar coefficients of friction, whereas PP has the highest value. However, the wear rate is significantly smaller for the WPC than for the other two materials. The higher stiffness and yield stress of the WPC minimises the plasticity inherent to the neat PP in the contact zone, resulting in a lower coefficient of friction and wear rate. Whereas in wood specimen generalised micro fisuration and delamination can be observed at the worn surface, the wood fibres embedded in WPC produces fewer wear debris, which is probably due to the restrained deformation of the collapsed and/or matrix filled cellular structure of wood fibres. So, the WPC has shown better wear performances than its neat constituents, polymer and wood.

The wear behaviour of PP, wood and wood reinforced PP (WPC) have been investigated and related to the microstructure of each material. WPC has higher density that PP and wood, and it is due to the fact that in WPC the cellular structure of wood is collapsed or PP filled.

WPC and wood have very similar μ, and PP presents the higher one. The higher strength and the lower temperature rise of the WPC, when compared with neat PP, stop the ploughing of the counterbody, and the resulting smaller contact area is the origin of the lower friction of coefficient. The increase of μ in the earlier stages of the WPC test is associated to the neat PP skin-layer, and the following stabilised value is achieved when this skin is eliminated and counterbody is in contact with PP matrix and wood reinforcement of WPC.

The wear rate of WPC is the lowest, the one of neat wood is 10 times higher and that of PP is the highest. The wear mechanism for PP is a combination of plastic flow and melting phenomenon, which are at the origin of its highest wear rate. For wood, the microfisuration and delamination induced by deformation are the main wear micromechanism. In WPC the wear mechanism of the wood reinforcement are different to those of neat wood, since the collapsed or PP-filled wood fibers into the WPC which reduces the buckling/ microfisuration/ delamination micromechanisms inherent to the cellular structure of wood.

Harsha and Jha [27] studied “Erosive wear studies of epoxy-based composites at normal incidence”. Erosive wear resistance has been evaluated for neat epoxy, unidirectional glass and carbon fibre reinforced epoxy composites and bi-directional E-glass fabric reinforced epoxy composite at normal incidence. Bi-directional glass fibre reinforced epoxy composite showed better erosive wear resistance than unidirectional fibre reinforced composites. This is due to the arrangement of glass fibres in bi-direction and is more helpful in absorbing considerable amount of impact energy during the fracture process than unidirectional composites. Erosion behaviour of these composites has been ascertained by correlating steady-state erosion with impingement angle, impact velocity and by plotting erosion efficiency (η) versus hardness map. It is broadly confirmed that semi-ductile erosion behaviour is operative in epoxy and its composites. Scanning electron microscopy (SEM) studies have been conducted to understand the wear mechanisms involved during the material removal process.

Based on the erosive wear studies of epoxy and its composites following conclusions are drawn:

1. The bi-directional glass fibre reinforced epoxy composite showed better wear resistance than unidirectional reinforced composites. The erosion behaviour of epoxy composites is controlled by the type of fibre and its arrangement.

2. The steady-state erosion rate of epoxy and its composites increased with increase in impact velocity from 25 to 60 m/s (approximately 31–95%).

3. The epoxy composites have shown peak erosion rate at 60° impingement angle at impact velocity of 25 m/s. The velocity exponents (n) in the present study are in the range of 1.68–3.0 and the values of erosion efficiencies vary from 1 to 24% at different impact velocities. Thus the erosion behaviour of epoxy and its composites has been broadly classified as semi-ductile.

4. Reinforcement of fibre increases erosion efficiency and hence the erosion rate of the composites which is due to the crack propagation in the brittle glass and carbon fibres and removal of large chunk of material as wear debris.

5. SEM studies of worn surfaces support the wear mechanisms involved and indicated pulverization of wear debris, exposure of fibres, micro-cracking, micro-cutting and cavities due to detachment of broken fibres from the resin matrix.

In the present work studies have been carried out to assess the Friction and Wear behaviour of Coir short fiber reinforced composite under controlled laboratory condition. A comprehensive picture of wear under different working conditions has been presented by conducting laboratory tests in pure abrasive mode using a pin-on-disc machine and studying them under SEM to know the wear mechanism.

CHAPTER 3
EXPERIMENTAL DETAILS

3.1 COMPOSITE FABRICATION

Unsaturated isophthalic polyester resin is used as polyester resin, 2% cobalt nephthalate (as accelerator) is mixed thoroughly in isophthalic polyester resin and then 2% methyl-ethyl-ketone-peroxide (MEKP) as hardener is mixed in the resin prior to reinforcement.

The coir fibers collected from coconut husks were dried. The approximate length of the coir fiber is about 5-10mm.Required weight percentage of coir fiber was then added to polyster with predetermined amount of hardener and accelerator and stirred by a glass rod in a glass container. The paste was then poured into test-tubes which inner walls were wax coated. Maximum amount of the paste was poured in order to avoid voids. The samples were then left for at least 24 hours to get hardened. Then, the test-tubes were broken in order to remove the sample from it. The samples were then belt polished to get a diameter of 12mm (sample holder diameter). The samples were then cut into different pieces of about 30mm length by hex saw and polished both of its surface(top & bottom).

Three different composition of samples were fabricated.

- Sample 1 – pure polyester
- Sample 2 – 10% coir fiber
- Sample 3 – 20% coir fiber
- Sample 4 – 30% coir fiber
- Sample 5 – 40% coir fiber
- Sample 6 – 50% coir fiber
- Sample 7 – 70% coir fiber

3.2 DENSITY & VOID FRACTION

The theoretical density of composite materials in terms of weight fraction can easily be obtained as for the following equations.

$$\rho_{ct} = \frac{1}{\left(\frac{Wf}{\rho f}\right)+\left(\frac{Wm}{\rho m}\right)}$$

Where, W and ρ represent the weight fraction and density respectively. The suffix f, m and ct stand for the fiber, matrix and the composite materials respectively. The actual density (ρ_{ce}) of the composite, however, can be determined experimentally by measuring its mass and volume. The volume fraction of voids (Vct) in the composites is calculated using the following equation:

$$V_{ct} = \frac{\rho ct - \rho ce}{\rho ct}$$

3.3 HARDNESS MEASUREMENT

The hardness values of the fabricated composites are determined by Vicker's microhardness tester with an applied load of 0.5Kgf.

3.4 WEAR TEST

3.4.1 ABRASIVE WEAR TEST APPARATUS

Test up used in the study of wear test is capable of creating reproducible abrasive wear situation for accessing the abrasive wear resistance of the prepared composite samples. It consists of a pin on disc, loading panel and controller.

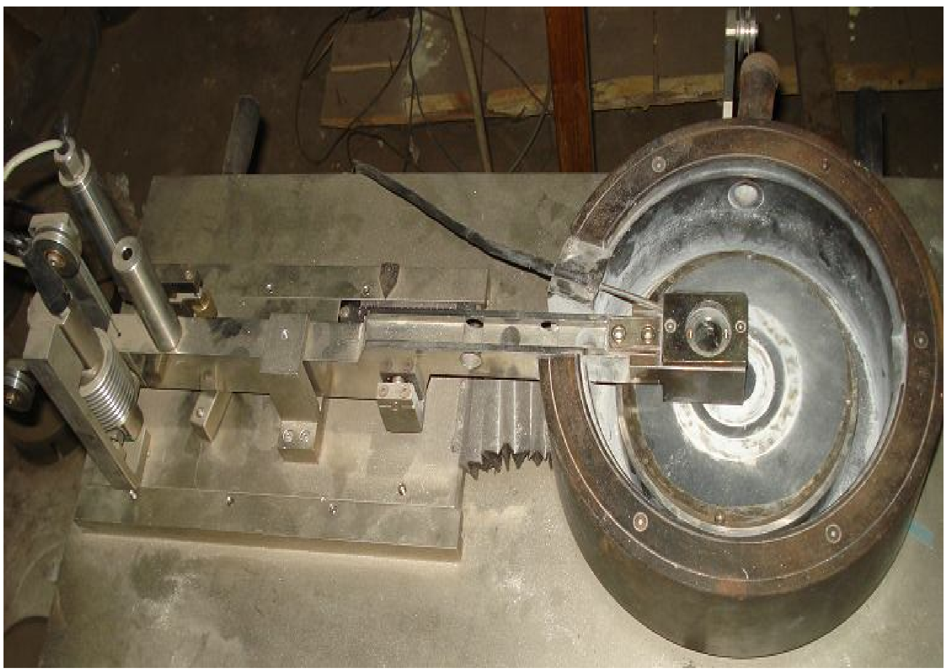

Figure 3.1 DUCOM Wear and Friction monitor machine

All the wear tests were carried out as per ASTM G-99 standard under unlubricated condition in a normal laboratory atmosphere at 50-60% relative humidity and a temperature of 28-32^{0}C using a "Ducom friction and wear monitor" machine. The mass loss in the specimen after each test was estimated by measuring the weight of the specimen before and after each test using an electronic weighing machine having accuracy up to 0.01mg. Care has been taken that the specimens under test are continuously cleaned with woolen cloth to avoid the entrapment of wear debris and to achieve uniformly in experiential procedure. Abrasive paper of required grit size is pasted with the hardened ground steel disc by an appropriate adhesive. The specimen was held stationary and a required normal load was applied through a lever mechanism.

Table 3.1 Specifications of the DUCOM wear and friction [28]

Parameter	unit	minimum	maximum
Wear disc	mm	100 x 6	
Disc speed	RPM	10	800
Pin diameter	mm	2	10
Pin length	mm	10	50
Ball diameter	mm	10	
Wear track dia	mm	10	80
Normal load	N	0	100
Frictional force	N	0	100

3.4.2 WEAR PARAMETERS

The variables involved in wear test are:

- Coir fiber weight/volume percentage
- Abrasive paper grit size
- Normal load
- Sliding velocity
- Sliding distance

Wear behaviour of the fabricated samples is combined affected by the above parameters. The effect of each individual parameter is studied in these experiments.

3.4.3 WEAR MEASUREMENT

Wear rate was estimated by measuring the mass loss in the specimen after each test and mass loss, Δm in the specimen was obtained. Cares have been taken after each test to avoid entrapment of wear debris in the specimen. Wear rate which relates to the mass loss to sliding distance (L) was calculated using the expression,

$W_r = \Delta m/L$

The volumetric wear rate Wv of the composite is relate to density (ρ) and the abrading time (t), was calculated using the expression,

$Wv = \Delta m / \rho t$

The friction force was measured for each pass and then averaged over the total number of passes for each wear test. The average value of co-efficient of friction, μ of composite was calculated from the expression,

$\mu = F_f / F_n$

Where F_f is the average friction force and F_n is the applied load.

For characterization of the abrasive wear behaviour of the composite, the specific wear rate is employed. This is defined as the volume loss of the composite per unit sliding distance and per unit applied normal load. Often the inverse of specific wear rate expresses in terms of the volumetric wear rate as

$Ws = W_v / V_s F_n$

where V_s is the sliding velocity

3.4.4 SEQUENTIAL WEAR MECHANISM

- As the sliding proceeds, with increase in applied load and/or sliding velocity, the polymer softens due to frictional heat generation.
- Then there is a plastic flow of the matrix material in the sliding direction causing surface deformation.
- Then the fragmented fibers/ filler particles, which normally have sharp edges, easily tear the matrix and gradually get aligned along the sliding direction.
- These particles by virtue of their size, shape, brittleness and high hardness influence modify the wear behavior of the composites. Longer duration of sliding results in formation of wear debris of different sizes and shapes.

3.5 DIELECTRIC BEHAVIOUR

The samples of dimension 12mm in diameter and 2.5 mm in thickness are coated with graphite paint on the opposite faces and heated for 15 min (at 100^0C) in oven for drying. Dielectric measurements are carried out at frequency of 1Hz to 10 MHz using HP-4192A LF Impedance Analyzer, connected with a data acquisition system. The temperature is controlled with a programmable oven. All the datas are collected at an interval of 5^OC, while heating at a rate of 5^OC/min at a frequency of 3000Hz is maintained. In dielectric analysis, each sample is placed between two gold electrodes (parallel plate sensors, TA instruments). The dielectric constant of composite are measured according to ASTM D5023.

The dielectric constant is expressed as;

$\varepsilon_r = Cl / (A\varepsilon_0)$

where, ε_r = dielectric constant

C = capacitance

l=thickness of the specimen

A = cross-sectional area of the specimen

ε_0= dielectric constant of vaccum i.e. 8.85x10-12 F/m

The dielectric behavior is obtained by measuring the dielectric constant and the dielectric loss at various temperature and frequency ranges.

CHAPTER 4
RESULTS & DISCUSSION

4.1 DENSITY & VOID FRACTION

The density of neat Polyester is 1.4 gm/cc and that of coir fiber is 0.758 gm/cc. The theoretical densities of the composites are determined by the rule of mixtures. The actual densities are measured by measuring its mass and volume, and then the void fraction is calculated.

Table 4.1 Density & Void fraction of composites of different fiber content.

Sample No.	Coir fiber, wt %	Theoritical density , gm/cc	Actual density, gm/cc	Void fraction, %
1	0	1.4	1.389	0.78
2	10	1.291	1.280	0.82
3	20	1.197	1.188	0.79
4	30	1.116	1.106	0.86
5	40	1.046	1.037	0.89
6	50	0.984	0.975	0.91
7	70	0.879	0.870	0.97

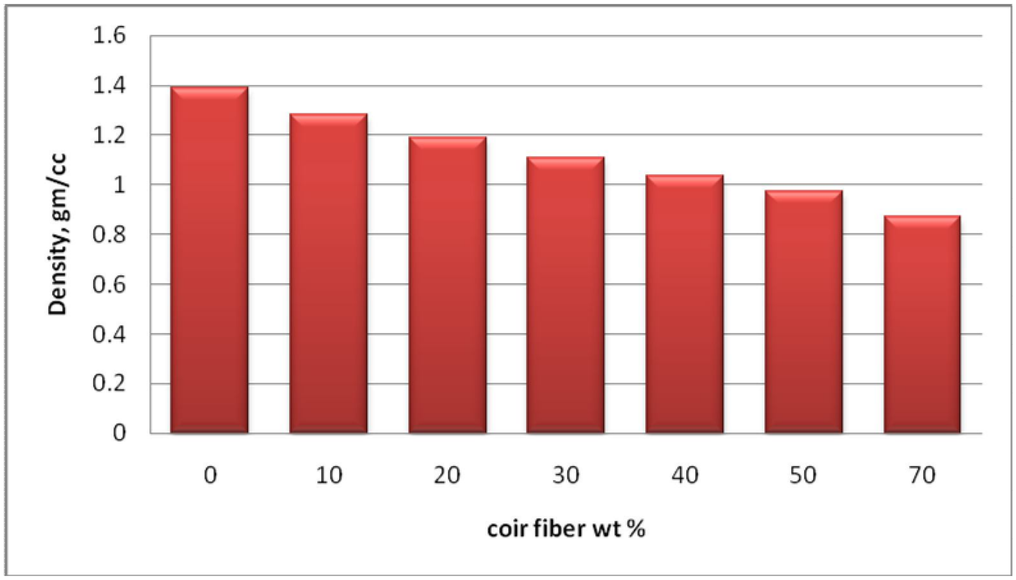

Figure 4.1 Variation of density with coir fiber content

4.2 HARDNESS MEASUREMENT

The hardness of each fabricated composite is measured by Vicker's micro hardness test machine using a 0.5 Kgf load.

Table 4.2 Vicker's hardness of composites with different fiber content

Sample No.	Coir fiber content (wt %)	Vicker's Hardness (HV)
1	0 (pure polyester)	18.8
2	10	24.7
3	20	29.6
4	30	36.2
5	40	39.4
6	50	41.5
7	70	44.5

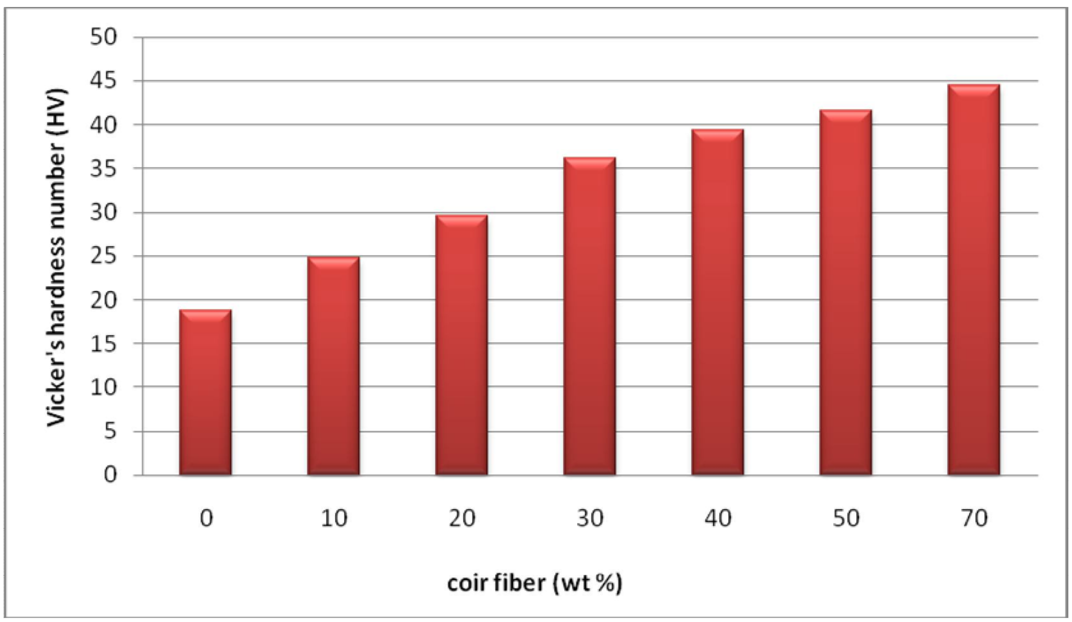

Figure 4.2 Variation of Hardness with fiber content

4.3 WEAR TEST RESULTS

The wear tests of coir fiber reinforced polyester composites were carried out with varying Normal load, sliding velocity, Abrasive particle grit size and Fiber percentage. The effect of individual parameter is tried to find out.

4.3.1 EFFECT OF NORMAL LOAD

The effect of normal load was studied by only varying the normal load, keeping all other parameters constant.

- For sample 1(coir fiber 10%)

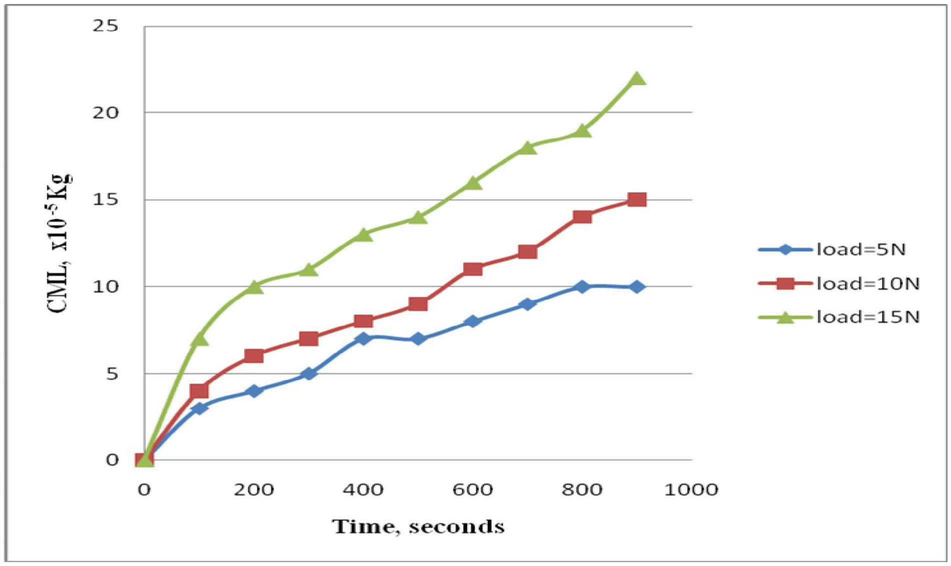

FIGURE 4.3-a
Variation of CML with time at abrasive 220, sliding velocity0.419m/S, coir fiber 10%

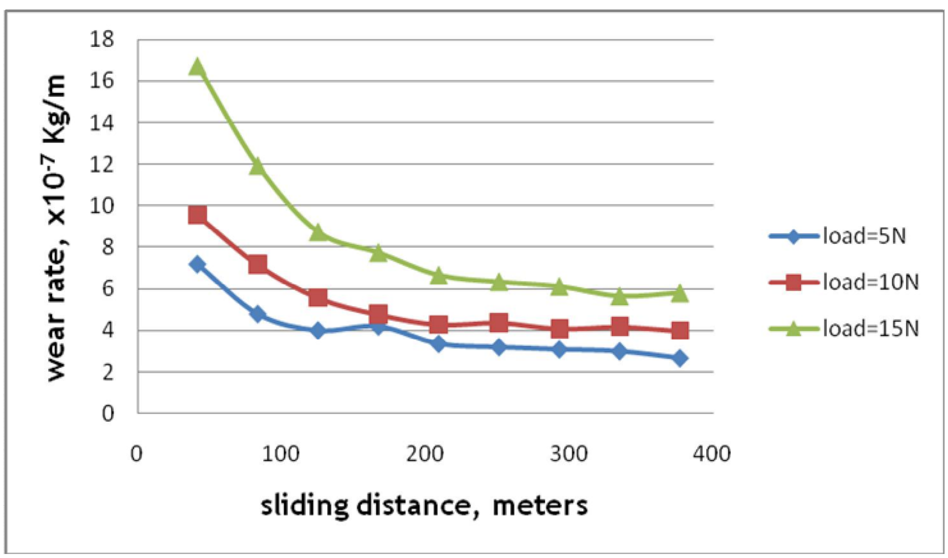

FIGURE 4.3-b
Variation of wear rate with sliding distance at abrasive 220, sliding velocity0.419m/S & coir fiber 10%.

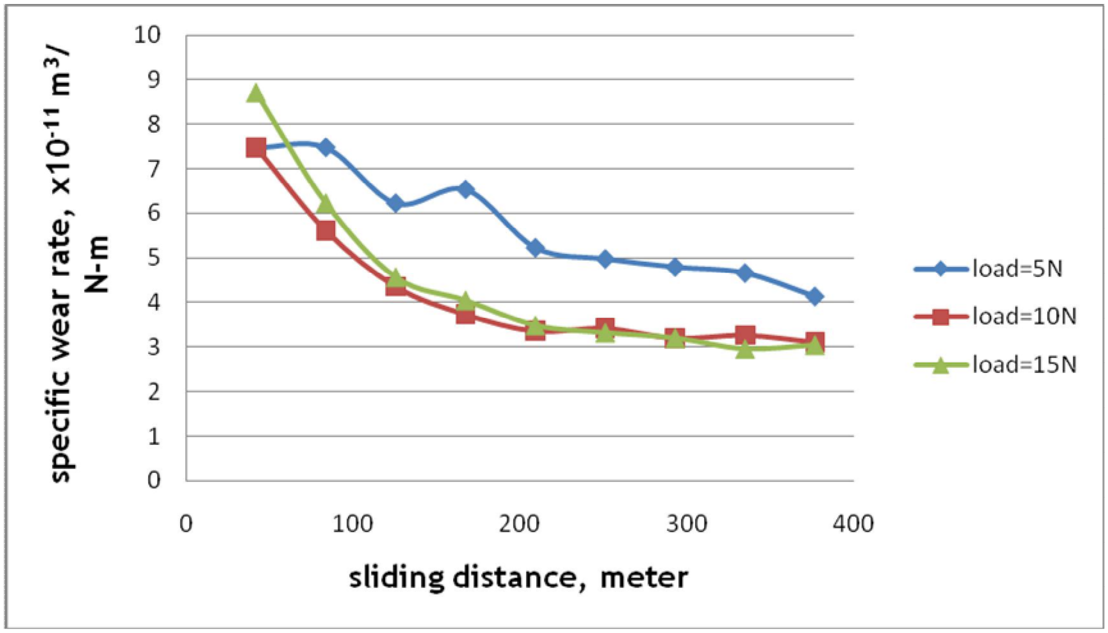

FIGURE 4.3-c
Variation of specific wear rate with sliding distance at abrasive 220, sliding velocity0.419m/S, coir fiber 10%

- For sample 2(coir fiber 20%)

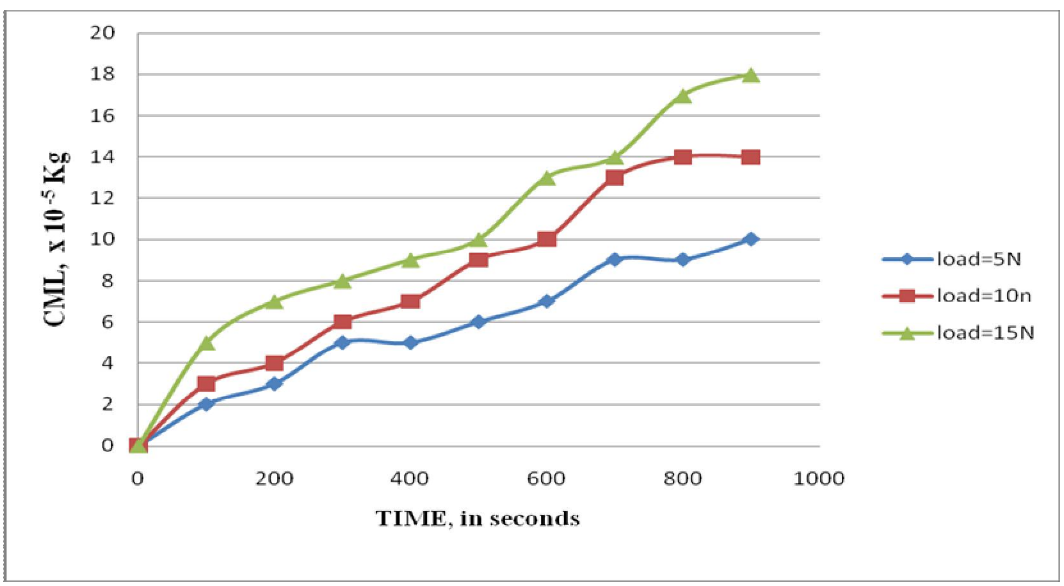

FIGURE 4.4-a
Variation of CML with time at abrasive 220, sliding velocity0.419m/S & coir fiber 20%

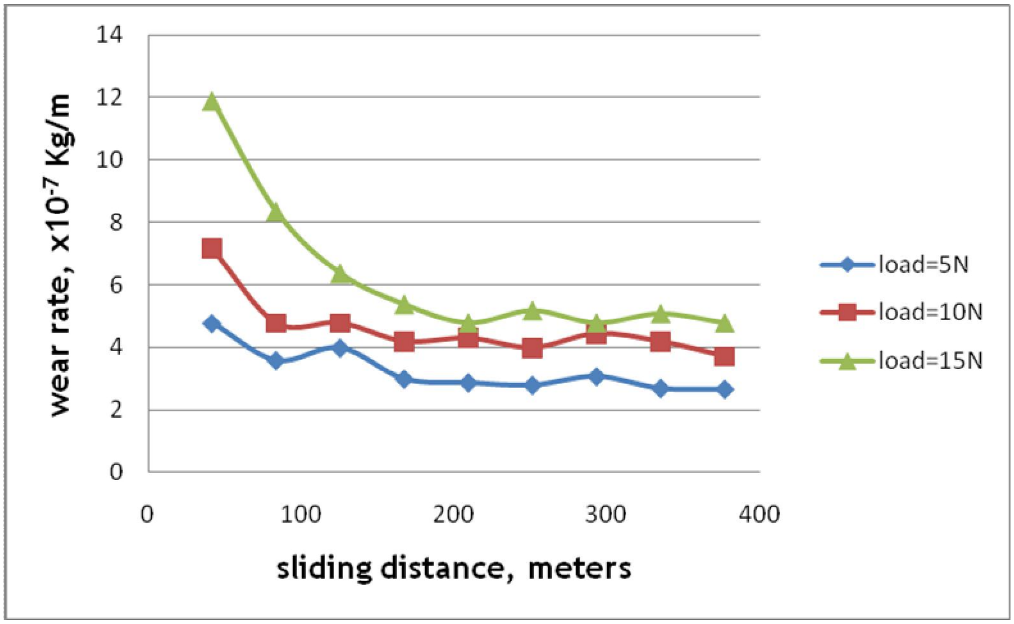

FIGURE 4.4-b

Variation of wear rate at sliding distance with abrasive 220, sliding velocity0.419m/S & coir fiber 20%

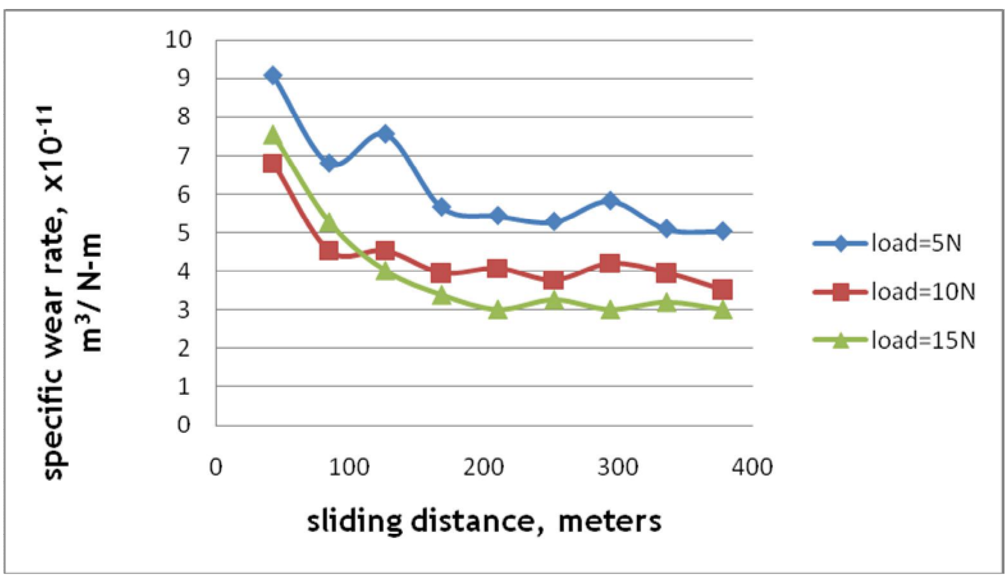

FIGURE 4.4-c

variation of specific wear rate with sliding distance at abrasive 220, sliding velocity0.419m/S, coir fiber 20%

- For Sample 3(coir fiber 30%)

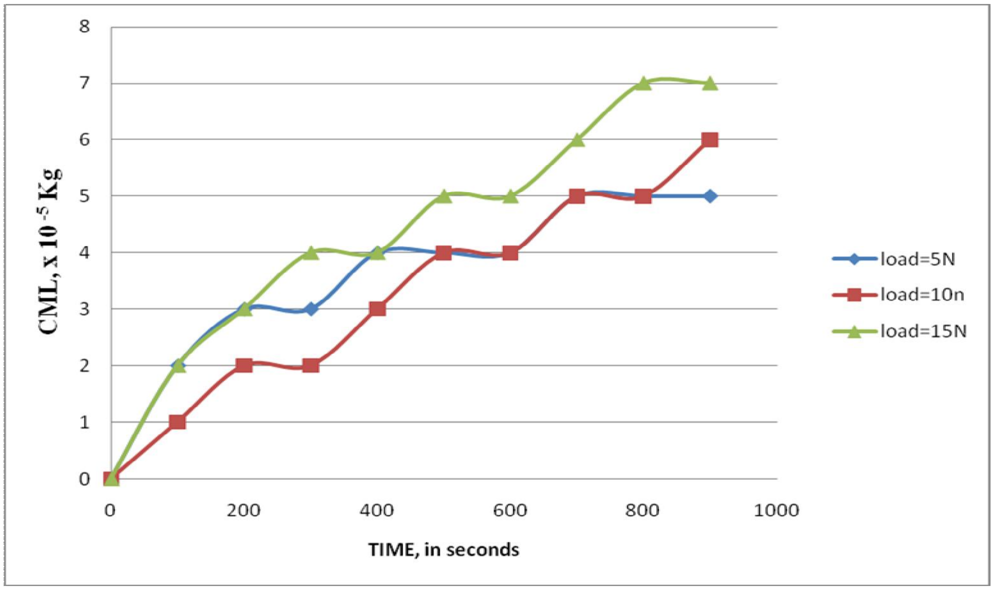

FIGURE 4.5-a
Variation of CML with time at abrasive 220, sliding velocity0.419m/S & coir fiber 30%

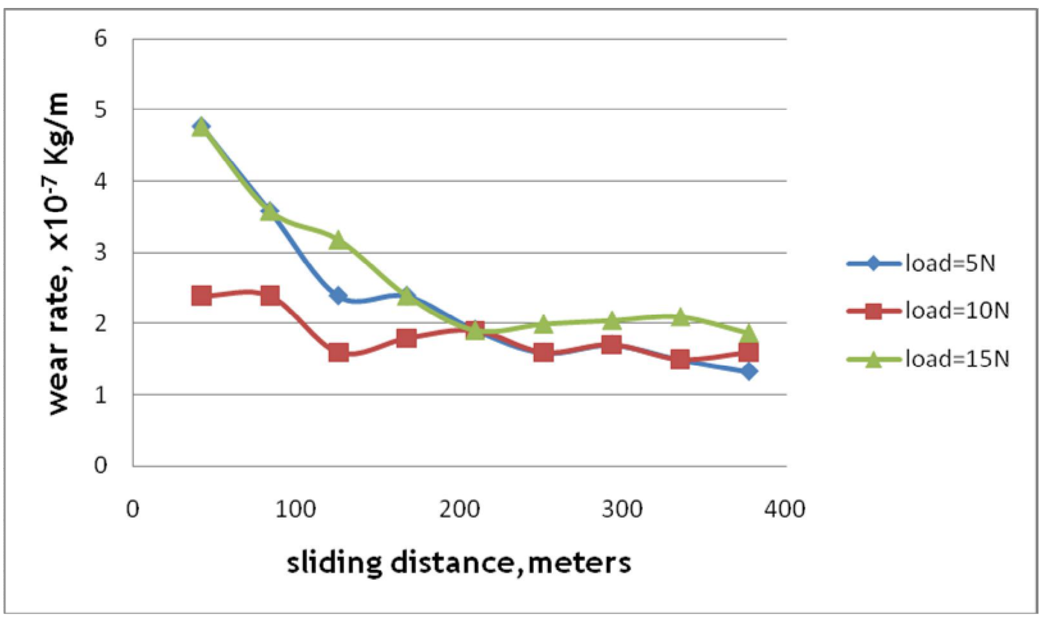

FIGURE 4.5-b
Variation of wear rate with sliding distance at abrasive 220, sliding velocity0.419m/S & coir fiber 30%

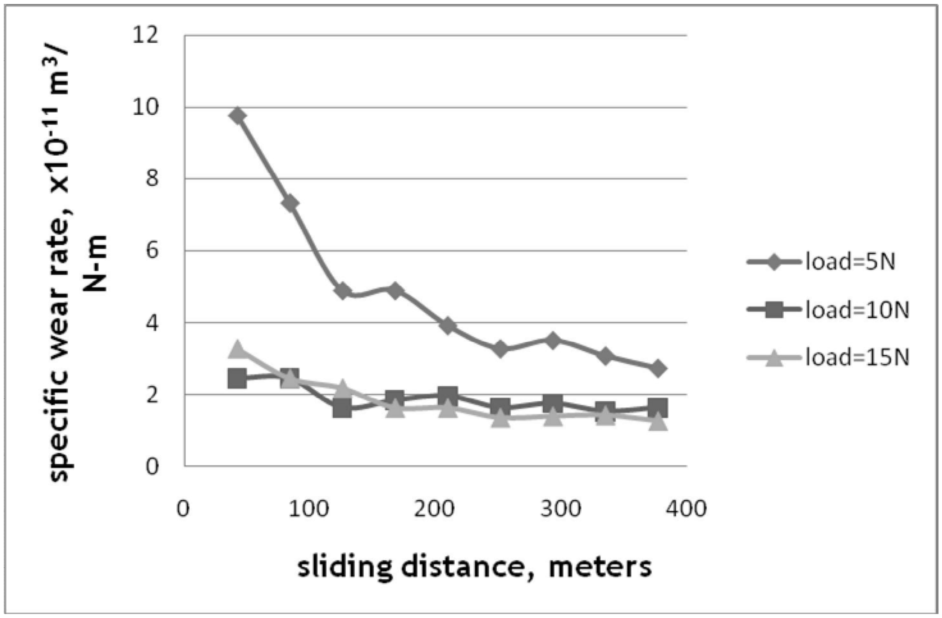

FIGURE 4.5-c
Variation of specific wear rate with sliding distance at abrasive 220, sliding velocity0.419m/S, coir fiber 30%

From all the above figures, i.e. fig. 4.3 to 4.5, it is observed that, with increase in applied load the CML (Cumulative Mass Loss) increases. This may be due to the reason that, the pressure between the surfaces i.e. the frictional force at the interface increases as the normal load increases. It can also be observed from the figures that initially the CML is more and also at a particular sliding distance the wear rate is higher for a higher normal load. After some distance of travel, the wear rate get stabilised and the material removal is also become low. At the same time it is also studied that the specific wear rate at a particular sliding distance is higher for a lower load.

4.3.2 EFFECT OF SLIDING VELOCITY

The effect of sliding velocity was studied by only varying the sliding velocity, keeping all other parameters constant.

- For sample 1(10% coir fiber)

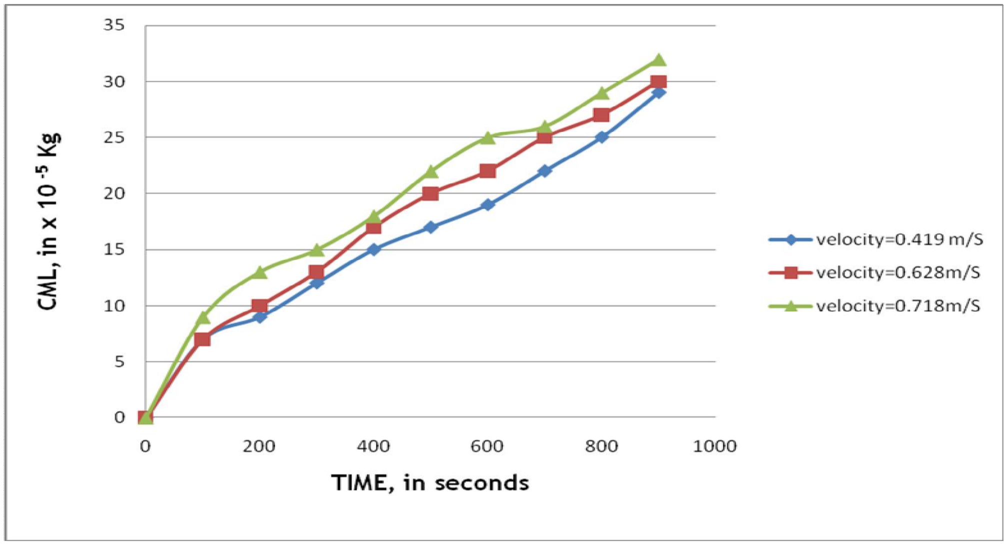

FIGURE 4.6

Variation of CML with time at Abrasive 220, Normal Load 10N & coir fiber 10%

- For sample 2(20% coir fiber)

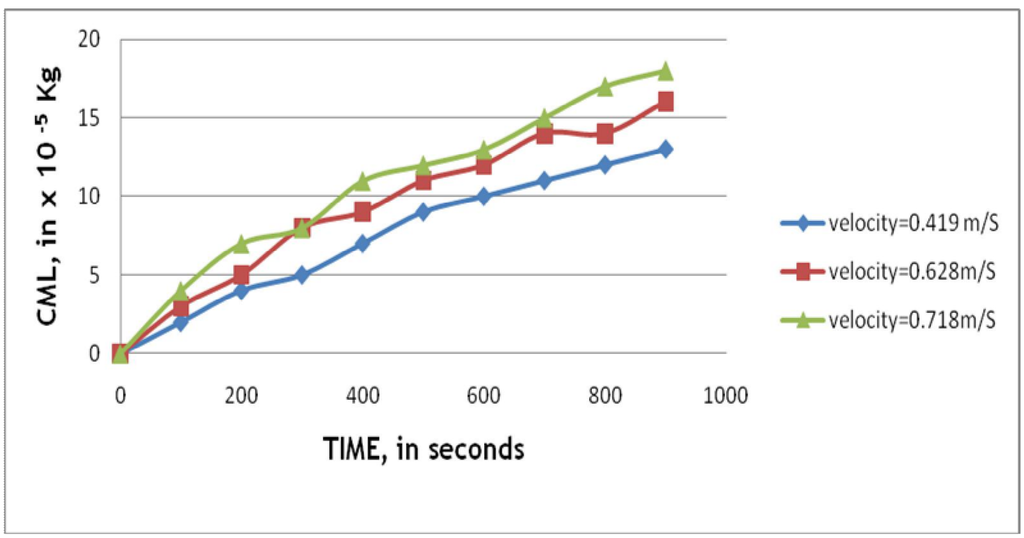

FIGURE 4.7

Variation of CML with time at Abrasive 220, Normal Load 10N & coir fiber 20%

- For sample 3(30% coir fiber)

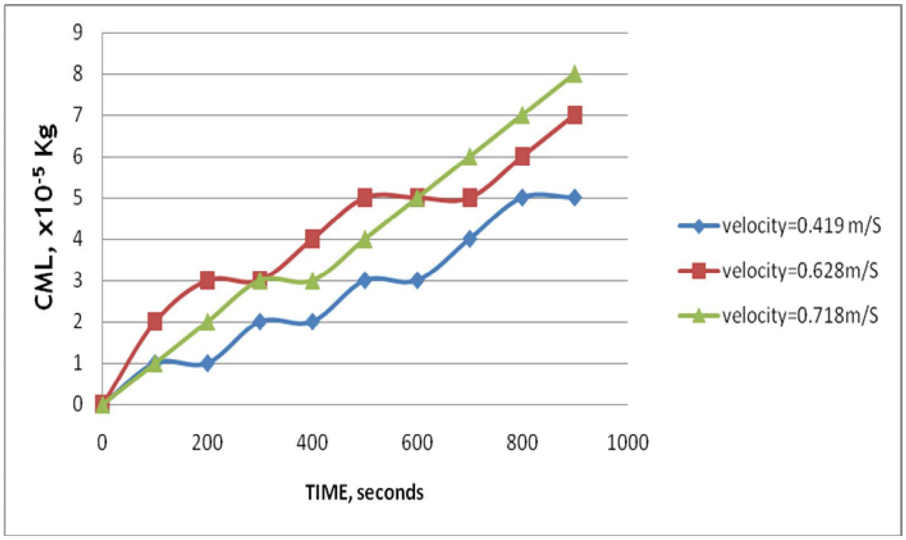

FIGURE 4.8

Variation of CML with time at Abrasive 220, Normal Load 10N & coir fiber 30%

From the figures 4.6 to 4.8, it can be visualized that as the sliding velocity increases the CML increases steadily with time.

4.3.3 EFFECT OF ABRASIVE GRIT SIZE

The effect of abrasive particle size was studied by only varying the abrasive grit size, keeping all other parameters constant.

- For sample 1 (coir fiber 10%)

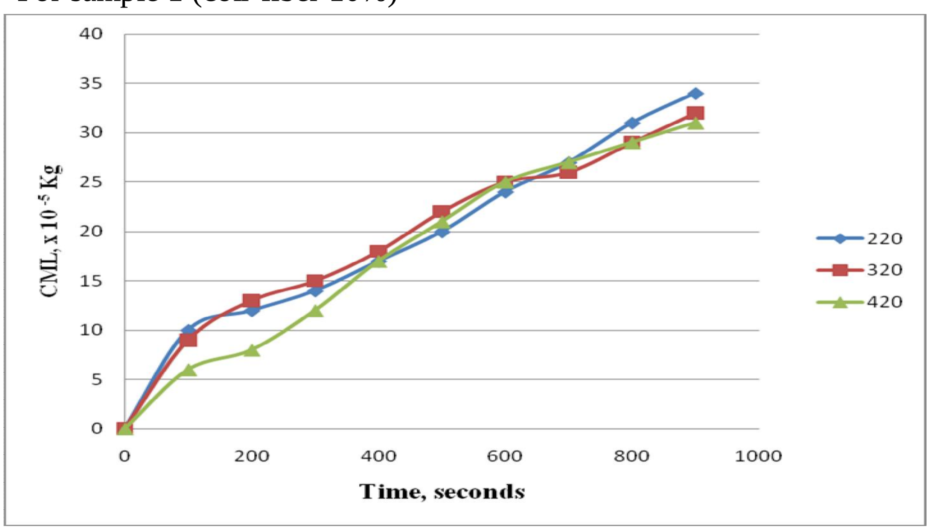

FIGURE 4.9-a

Variation of CML with time at sliding velocity 0.718m/S, Normal Load 10N & coir fiber 10%

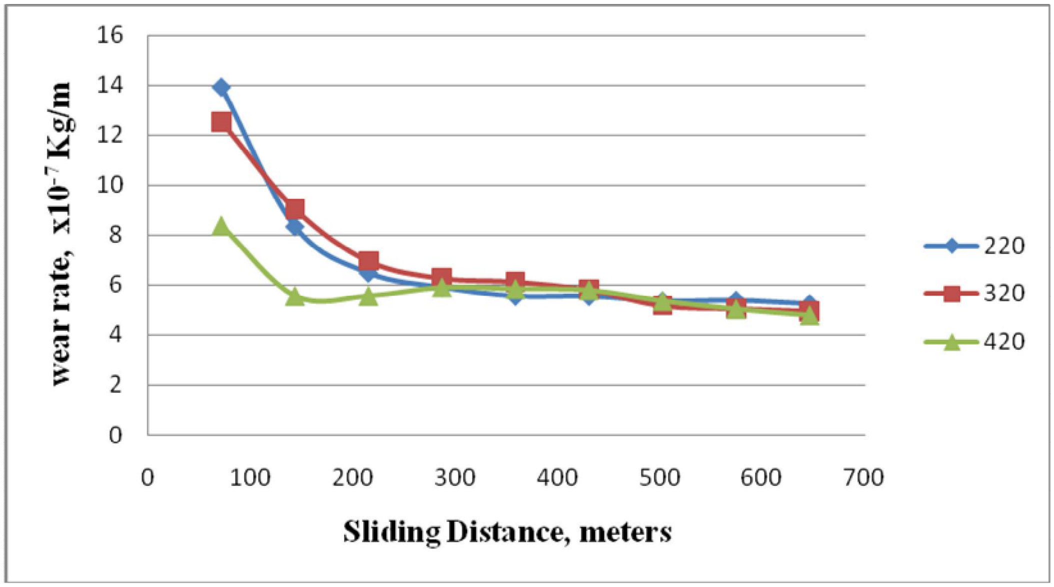

FIGURE 4.9-b

variation of wear rate with sliding distance at sliding velocity 0.718m/S, Normal Load 10N & coir fiber 10%

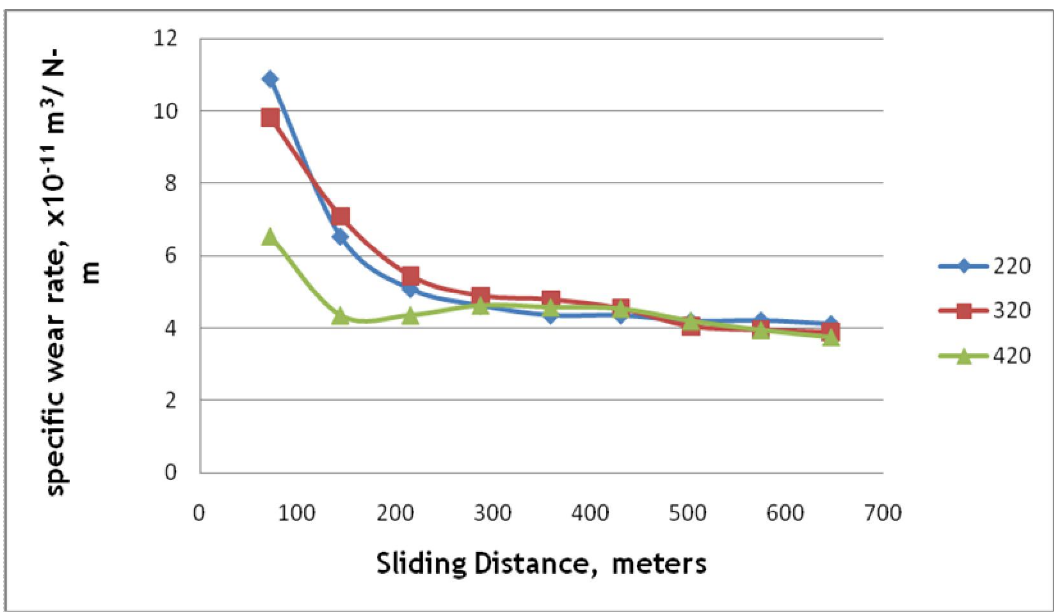

FIGURE 4.9-c

variation of specific wear rate with sliding distance at sliding velocity 0.718m/S, Normal Load 10N & coir fiber 10%

- For sample 2 (coir fiber 20%)

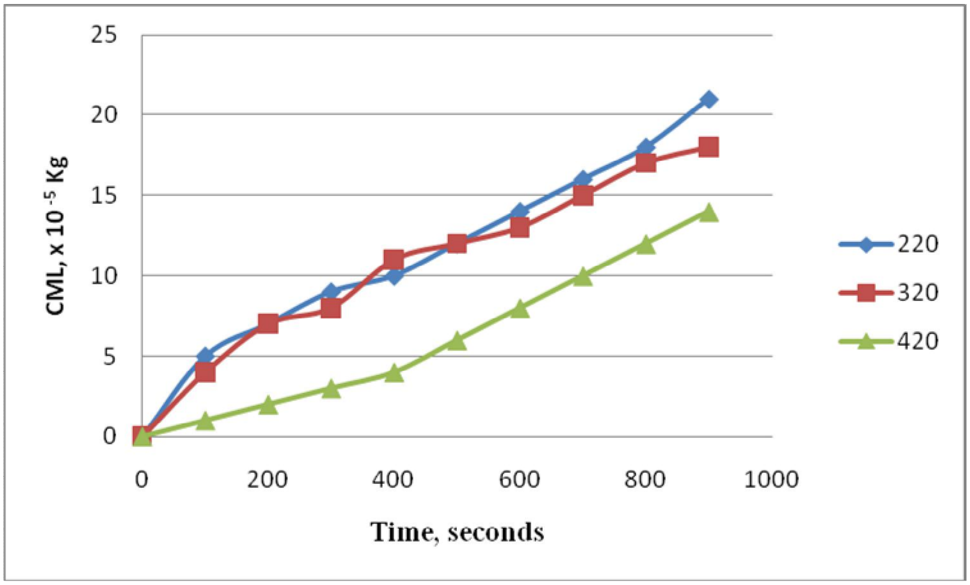

FIGURE 4.10-a
variation of CML with time at time at 0.718m/S, Normal Load 10N & coir fiber 20%

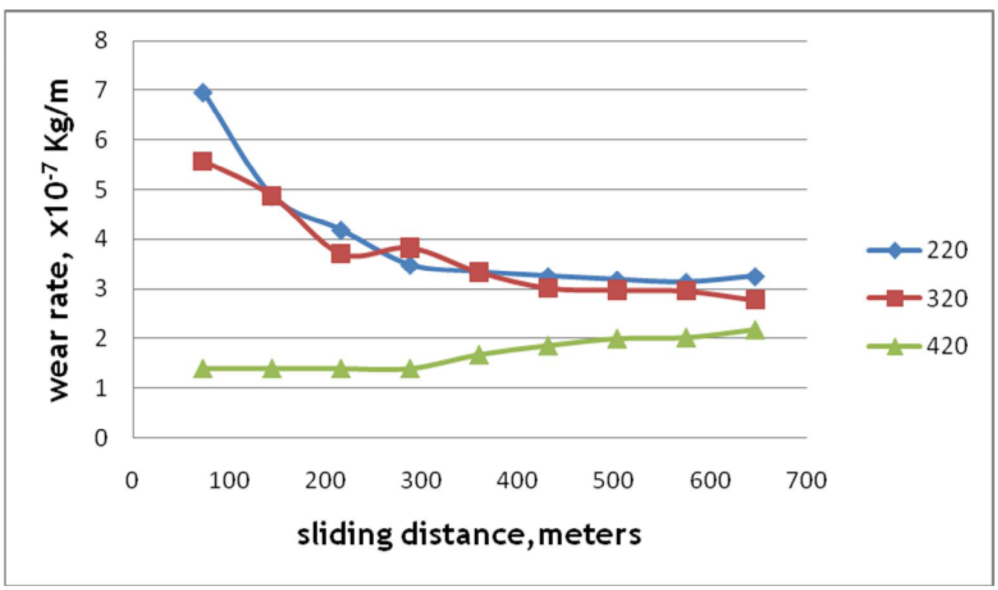

FIGURE 4.10-b
variation of wear rate with sliding distance at sliding velocity 0.718m/S, Normal Load 10N & coir fiber 20%

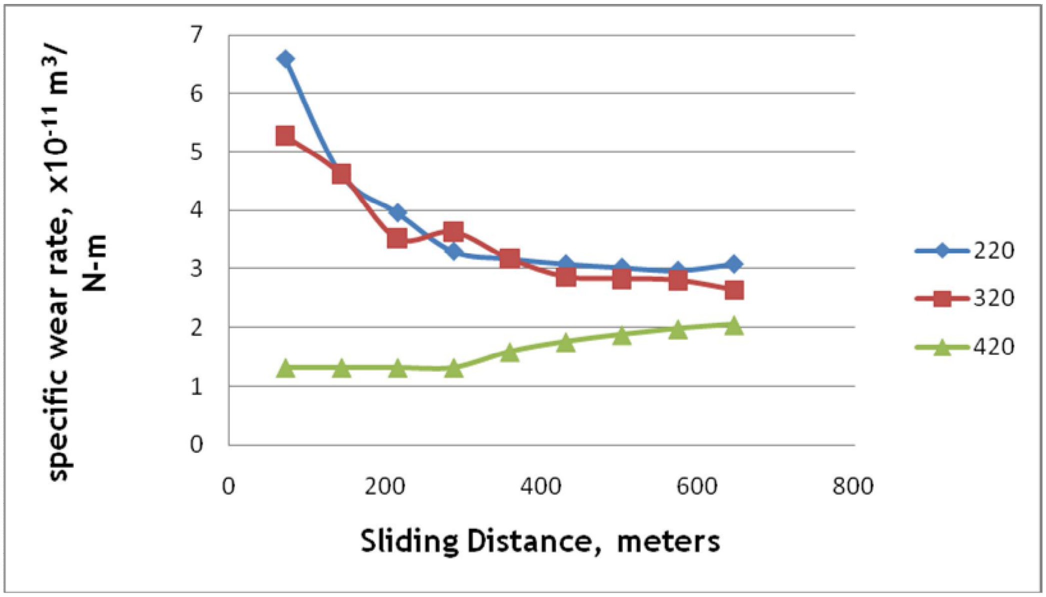

FIGURE 4.10-c
variation of specific wear rate with sliding distance at sliding velocity 0.718m/S, Normal Load 10N & coir fiber 20%

- For sample 3 (30% coir fiber)

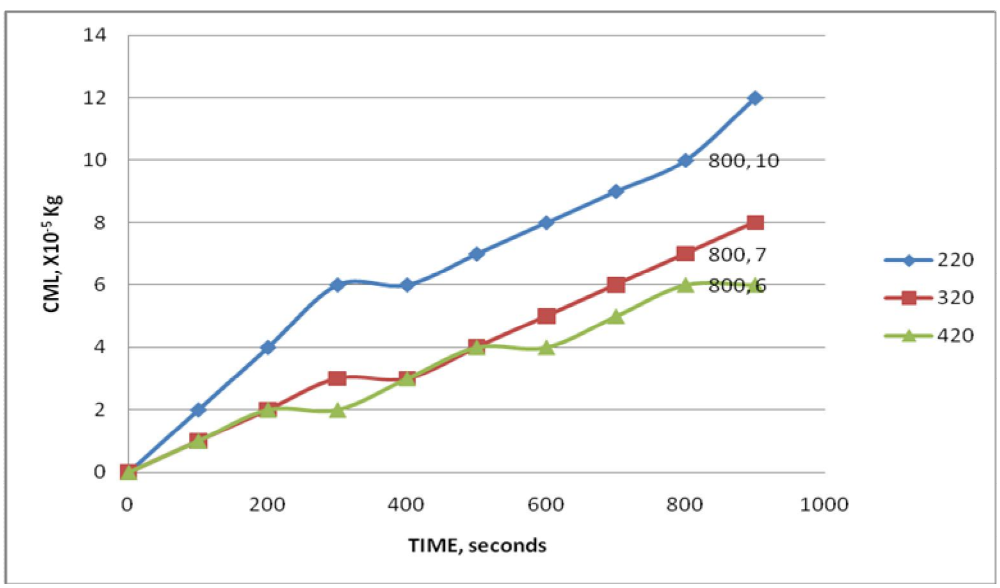

FIGURE 4.11-a
variation of CML with time at sliding velocity 0.718m/S, Normal Load 10N & coir fiber 30%

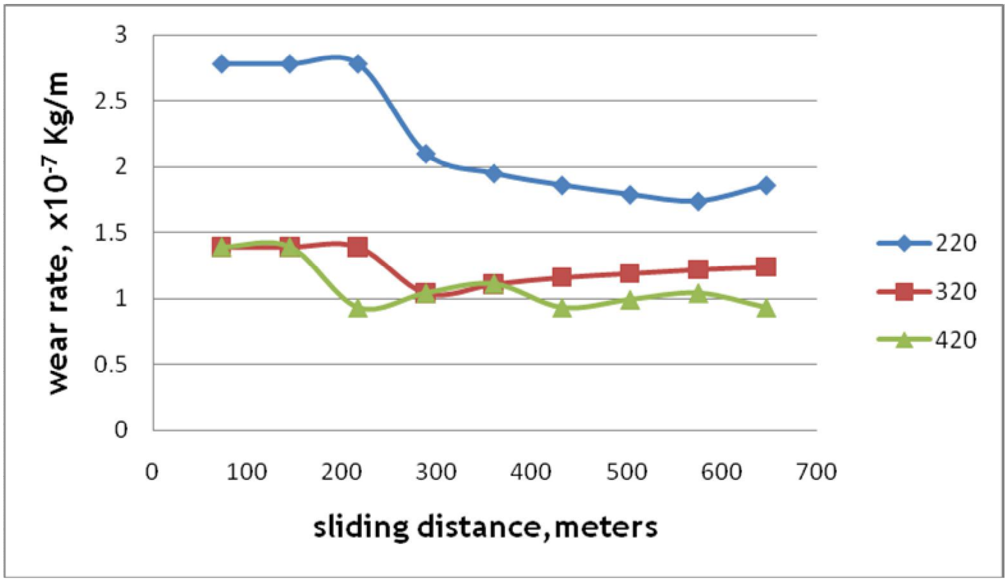

FIGURE 4.11-b
variation of wear rate with sliding distance at sliding velocity 0.718m/S, Normal Load 10N & coir fiber 30%

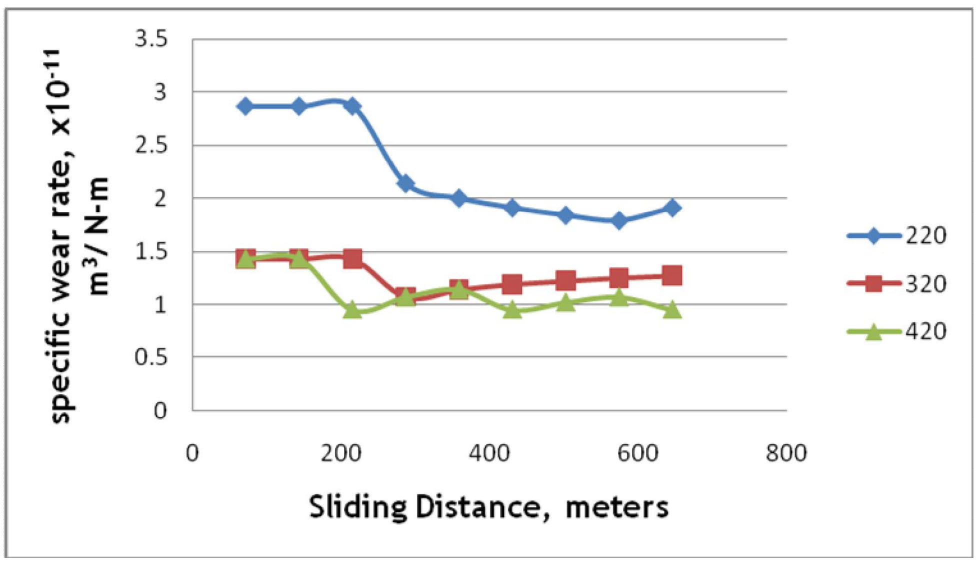

FIGURE 4.11-c
variation of specific wear rate with sliding distance at sliding velocity 0.718m/S, Normal Load 10N & coir fiber 30%

From the figures 4.9 to 4.11 it is found that, with increase in abrasive grit size, the CML increases irrespective of time length of experimentation. The same trend has also been observed for wear rate & specific wear rate (i.e. decreasing trend) with decrease in abrasive grit size (i.e.

from 420 to 220) at any particular sliding distance This may be due to the deeper penetration with larger particle size which enhances the material removal from the composite surface.

4.3.4 EFFECT OF REINFORCEMENT

The effect of fiber reinforcement was studied by only varying the fiber percentage, keeping all other parameters constant.

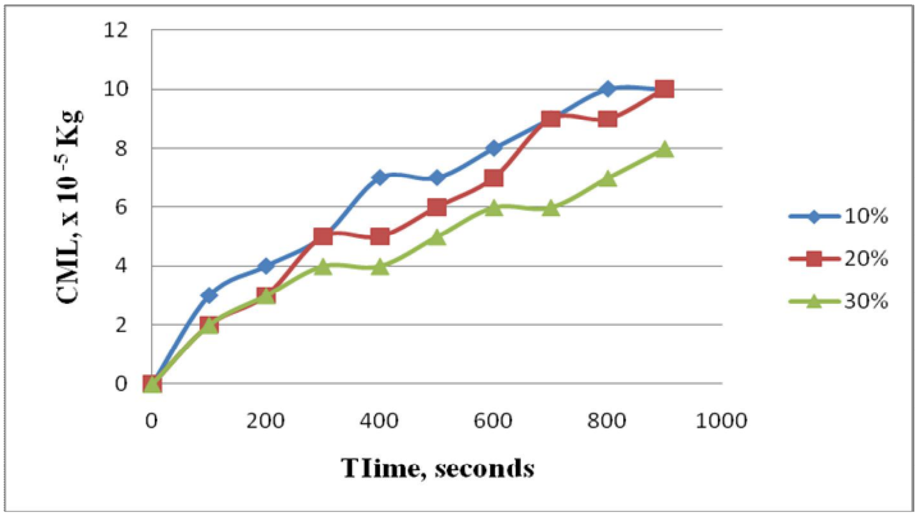

FIGURE 4.12-a
Variation of CML with time at abrasive 220, Normal load 5N, Sliding velocity 0.419 m/S.

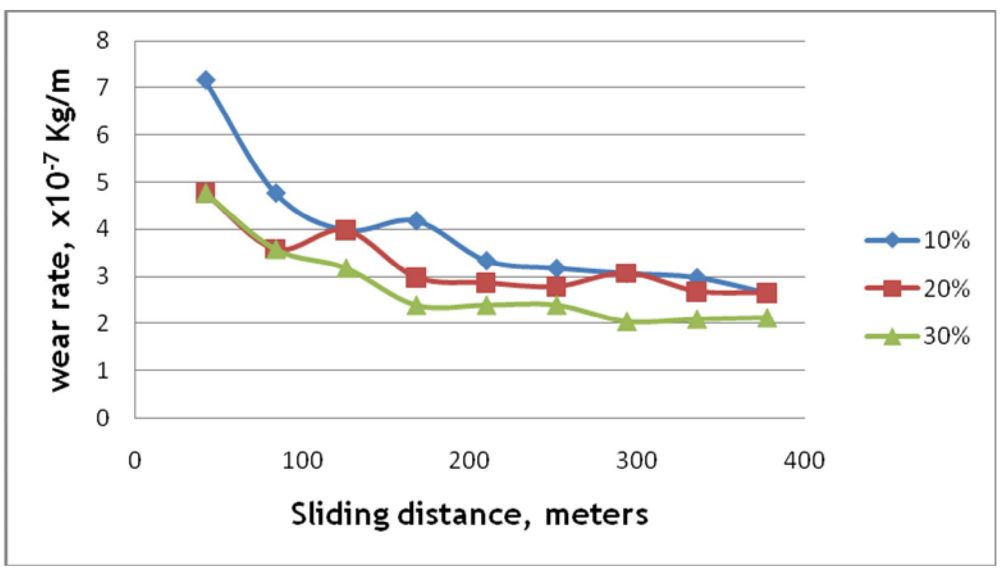

FIGURE 4.12-b
Variation of wear rate with sliding distance at abrasive 220, Normal load 5N, Sliding velocity 0.419 m/S.

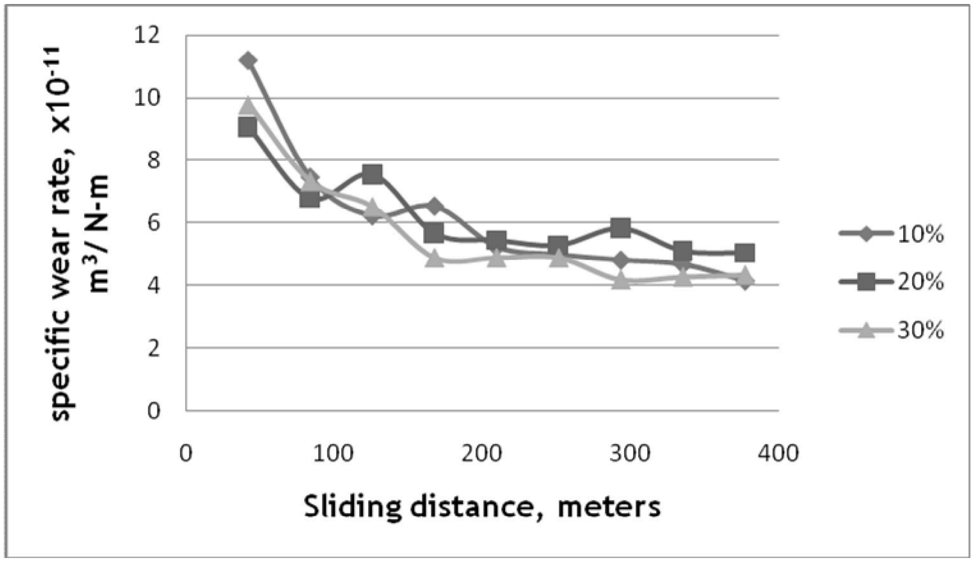

FIGURE 4.12-c

Variation of specific wear rate with sliding distance at abrasive 220, Normal load 5N, Sliding velocity 0.419 m/S.

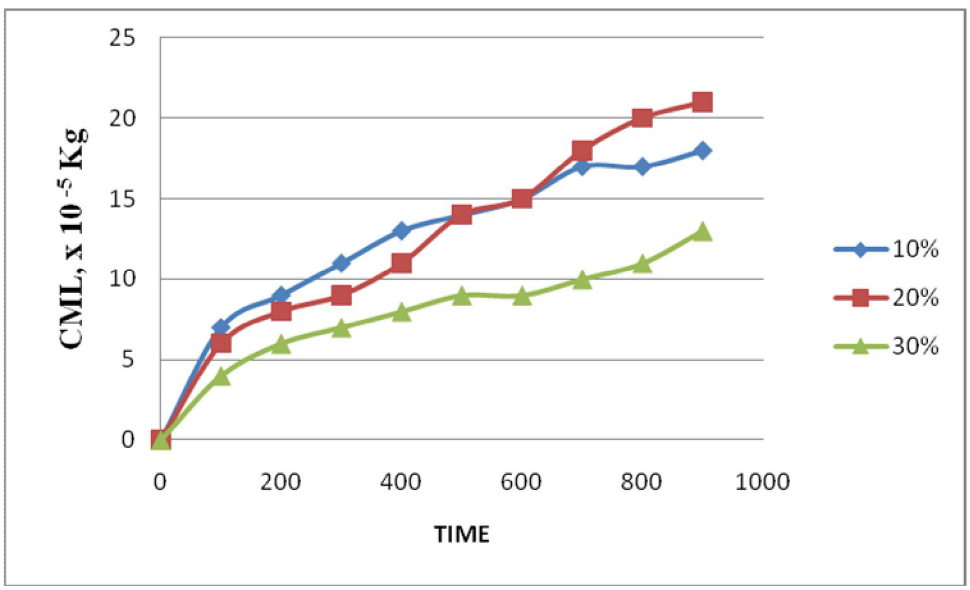

FIGURE 4.13-a

Variation of CML with time at abrasive 220, Normal load 10N, Sliding velocity 0.628 m/S.

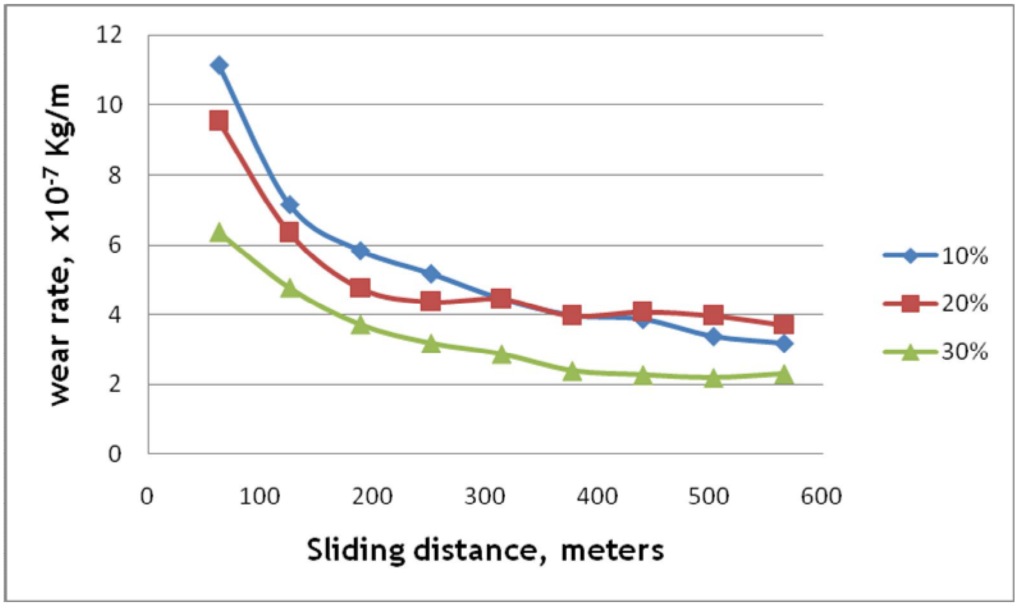

FIGURE 4.13-b
Variation of wear rate with sliding distance at abrasive 220, Normal load 10N, Sliding velocity 0.628 m/S.

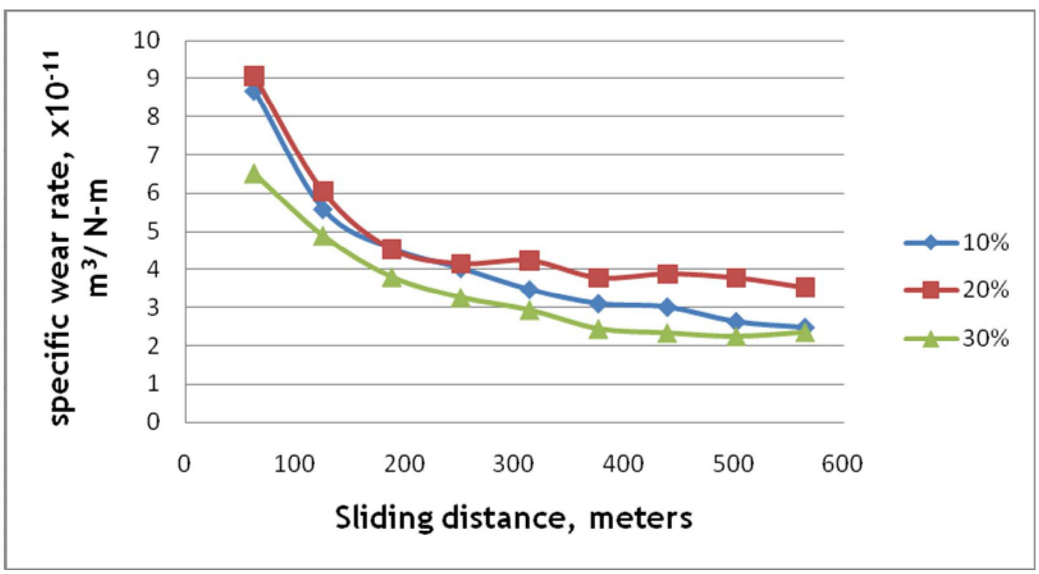

FIGURE 4.13-c
Variation of specific wear rate with sliding distance at abrasive 220, Normal load 10N, Sliding velocity 0.628 m/S.

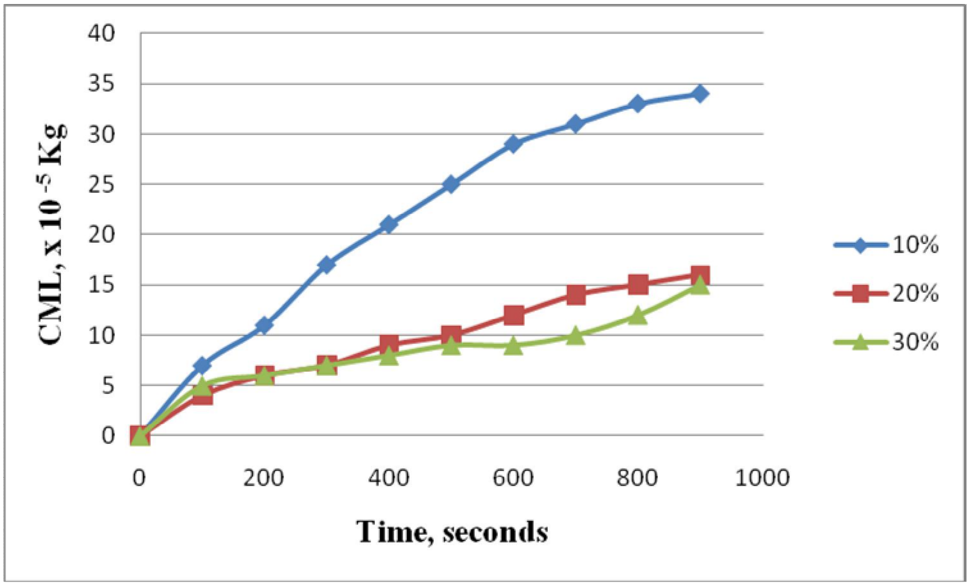

FIGURE 4.14-a
Variation of CML with time at abrasive 220, Normal load 15N, Sliding velocity 0.718 m/S

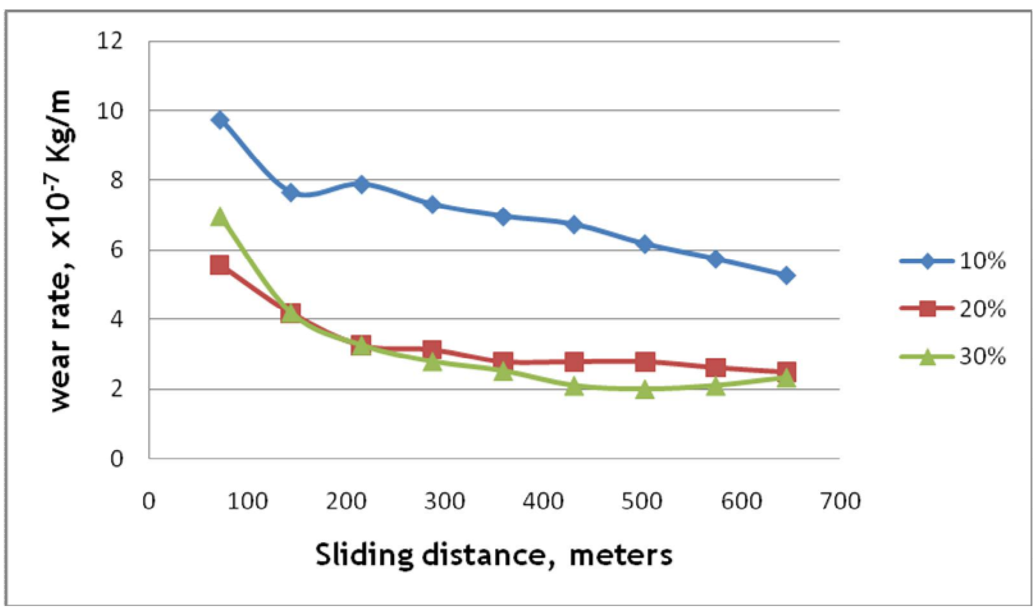

FIGURE 4.14-b
Variation of wear rate with sliding distance at abrasive 220, Normal load 15N, Sliding velocity 0.718 m/S.

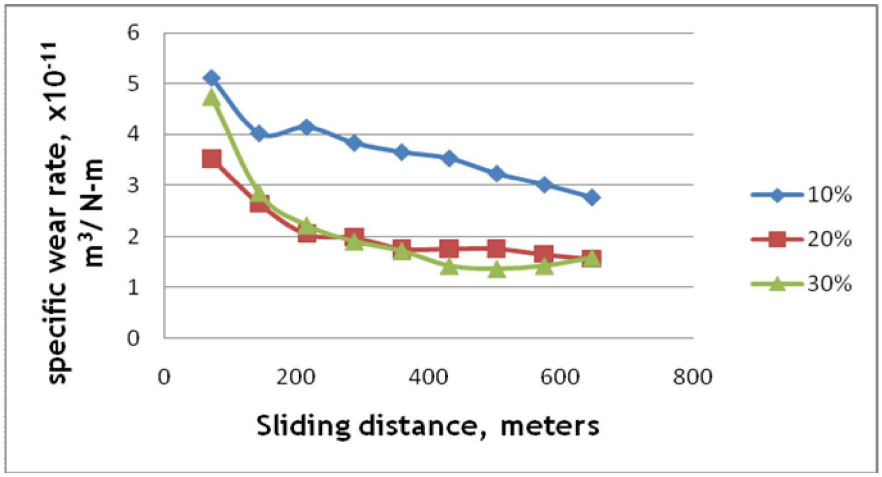

FIGURE 4.14-c
Variation of specific wear rate with sliding distance at abrasive 220, Normal load 15N, Sliding velocity 0.718 m/S.

From figures 3.10 to 3.12 it is observed that, with increase in fiber percentage in the composite, the CML decreases. The same trend is also noticed for wear rate & specific wear rate (i.e. decrease) with increase in fiber percentage, at any certain sliding distance.

4.4 DISCUSSION

In most of the cases it was seen that the mass loss due to abrasive wear is rapid at the initial stage and goes on decreasing with increase in time/distance travelled. As a consequence of this, it has also been observed that the wear rate & specific wear rate also decreases as the sliding distance increases and assumes to be more or less constant after certain sliding distance. A general wear curve as obtained from the Wear and Friction monitor machine is given below.

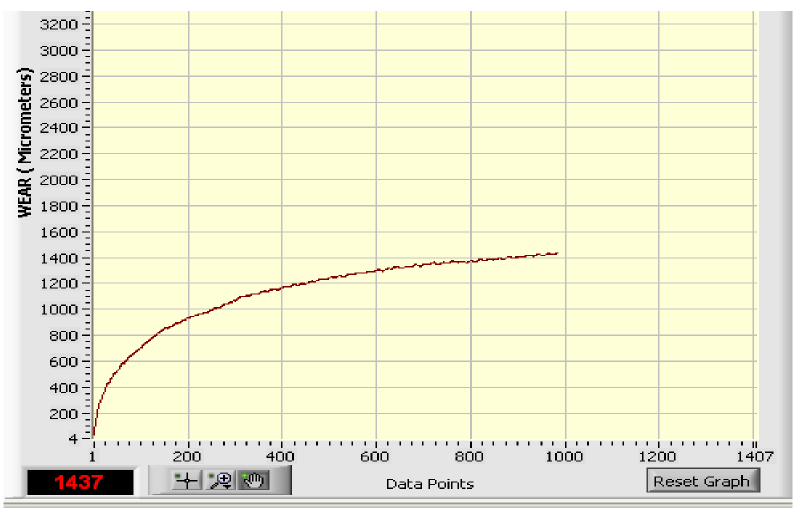

Figure 4.15 A Typical Wear Curve

The typical wear curve implies that initially the wear rate is high and after certain time it takes a stabilizing trend. This indicates the operation of two different wear mechanisms during wear process. Initially the abrasion mechanism dominates irrespective of the applied load and velocity; at further time length the adhesive wear mechanism might be dominating for which the wear rate takes a stabilization trend. The increase in the percentage of reinforcement helps in decreasing the rate of wear of the composite. There is also a possibility that, the matrix get softened with increasing the abrasion time which helps in decreasing the wear rate.

4.5 SCANNING ELECTRON MICROSCOPY

The worn surfaces of the composite samples are observed with Scanning Electron Microscope (JEOL JSM-6480LV) and the photographs are taken at 100X & 500X magnifications.

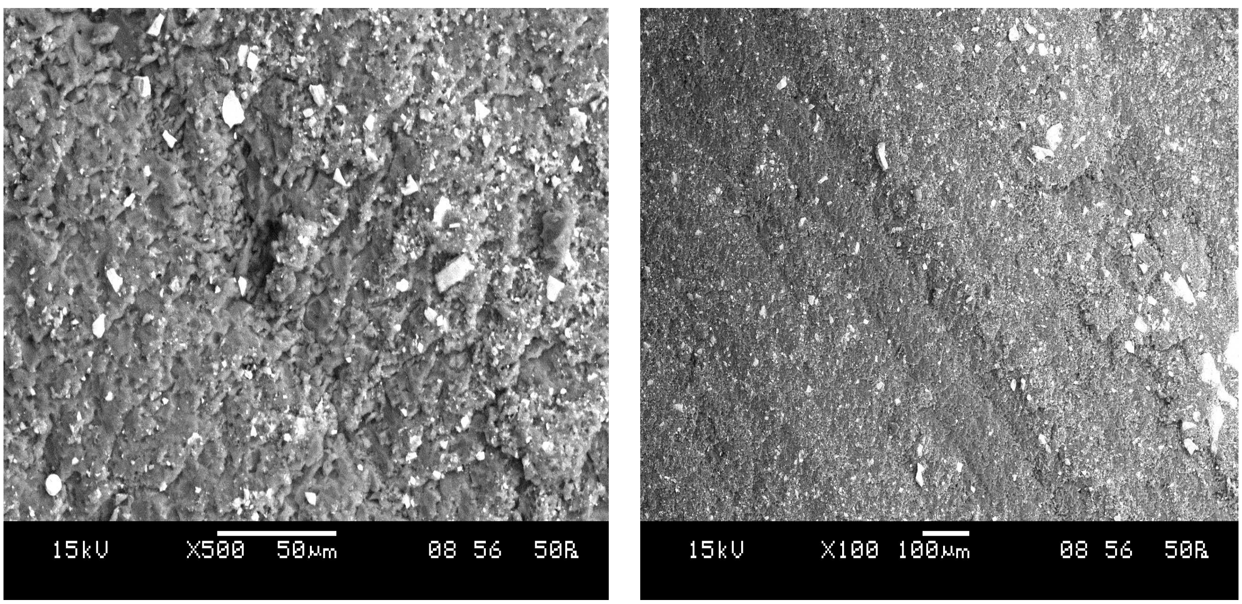

FIGURE 4.16

The worn surface of the composite with Abrasive 220, Normal Load 5N, Sliding Velocity 0.718 m/S, Coir Fiber 10% after 900 seconds.

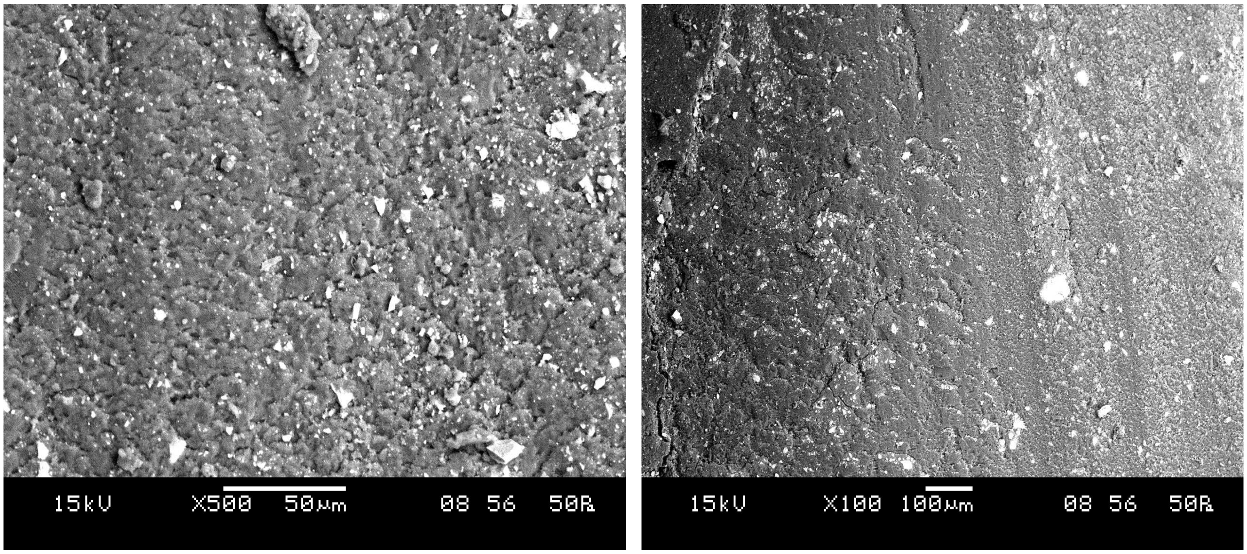

Figure 4.17

The worn surface of the composite with Abrasive 220, Normal Load 5N, Sliding Velocity 0.718 m/S, Coir Fiber 20% after 900 seconds.

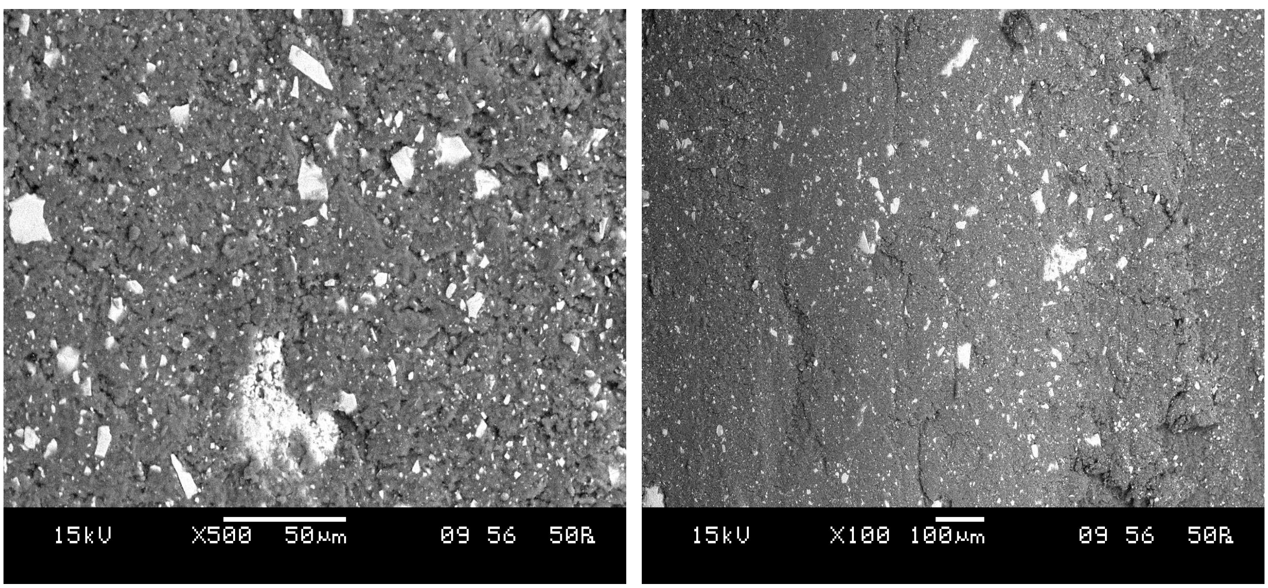

FIGURE 4.18

The worn surface of the composite with Abrasive 220, Normal Load 5N, Sliding Velocity 0.718 m/S, Coir Fiber 30% after 900 seconds.

Comparing the figures 4.16 to 4.18 it is seen that, with increase in the reinforcement percentage i.e. from 10 to 30%, there is a markable change on the surface morphology. The composite containing lower amount of reinforcement i.e. 10% coir fiber, deep grooves are observed, whereas with increasing reinforcement percentage the surface becomes smoother. However, at higher percentage of reinforcement i.e. 30% coir fiber some cracks are seen spreading in random directions in the matrix.

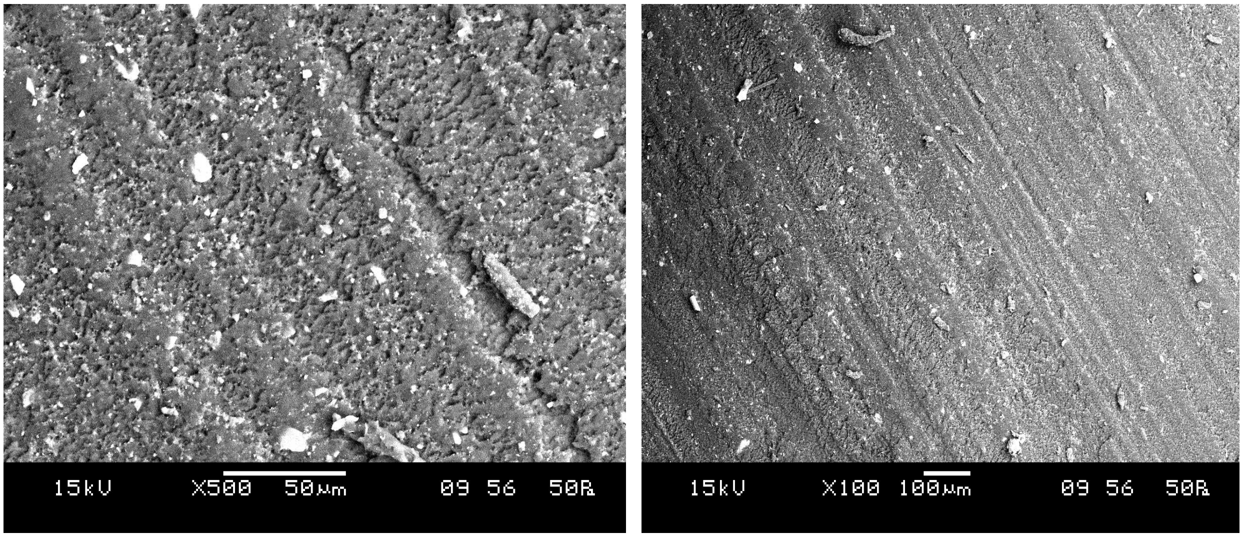

FIGURE 4.19

The worn surface of the composite under Abrasive 220, Normal Load 15N, Sliding Velocity 0.718 m/S, Coir Fiber 10% after 900 seconds.

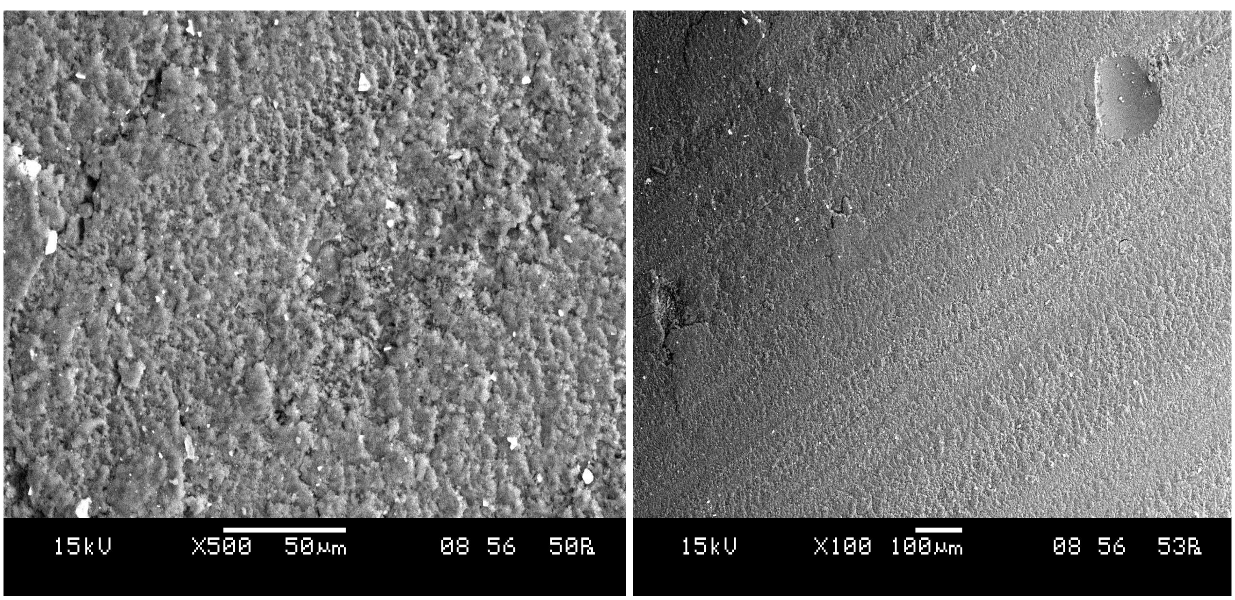

FIGURE 4.20

The worn surface of the composite under Abrasive 220, Normal Load 15N, Sliding Velocity 0.718 m/S, Coir Fiber 20% after 900 seconds.

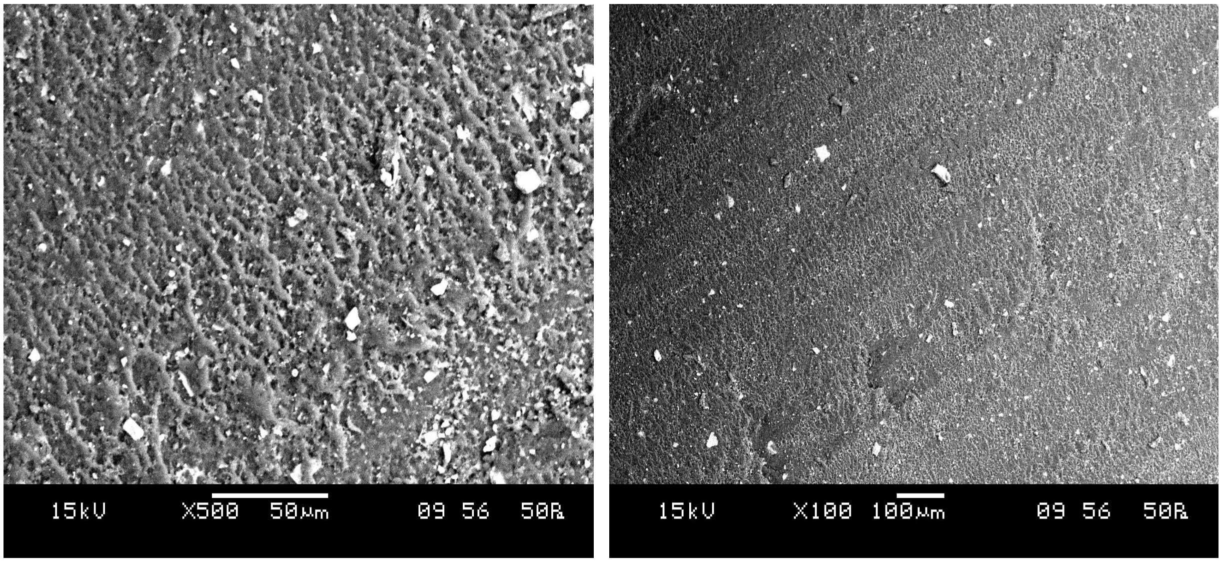

FIGURE 4.21

The worn surface of the composite under Abrasive 220, Normal Load 15N, Sliding Velocity 0.718 m/S, Coir Fiber 30% after 900 seconds.

With increase in applied load (figure 4.19 to 4.21) the surface morphology of the worn samples are different. Although the grooving trend is similar but material removal may be due to micro ploughing which is evidenced from the fact that with increase in filler content the micro grooves are becoming smaller in size.

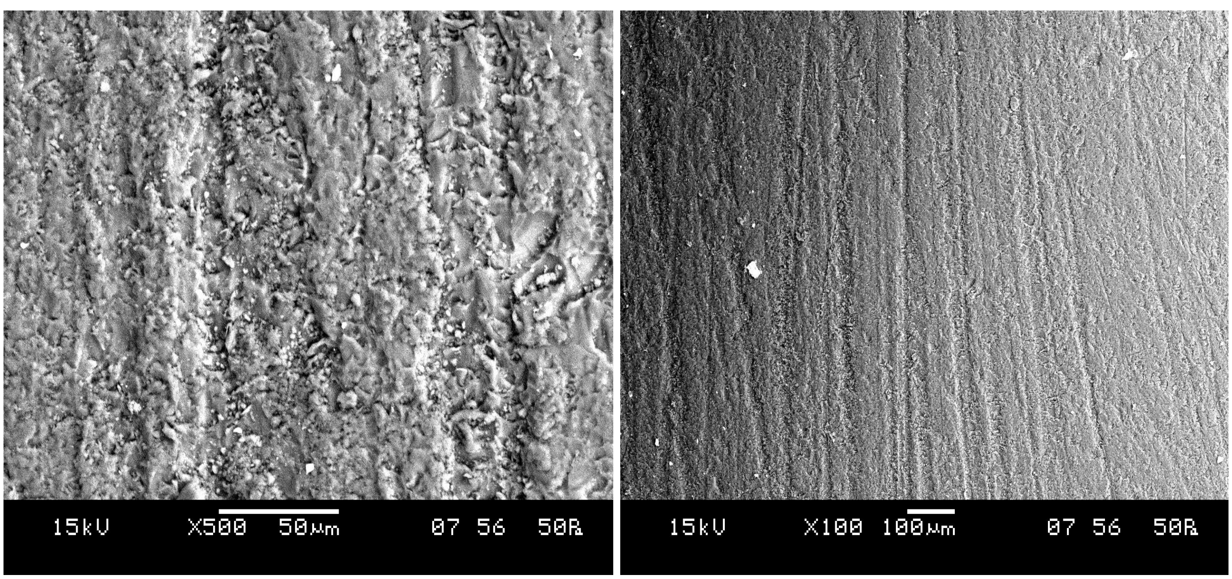

FIGURE 4.22

The worn surface of the composite under Abrasive 420, Normal Load 15N, Sliding Velocity 0.718 m/S, Coir Fiber 10% after 900 seconds.

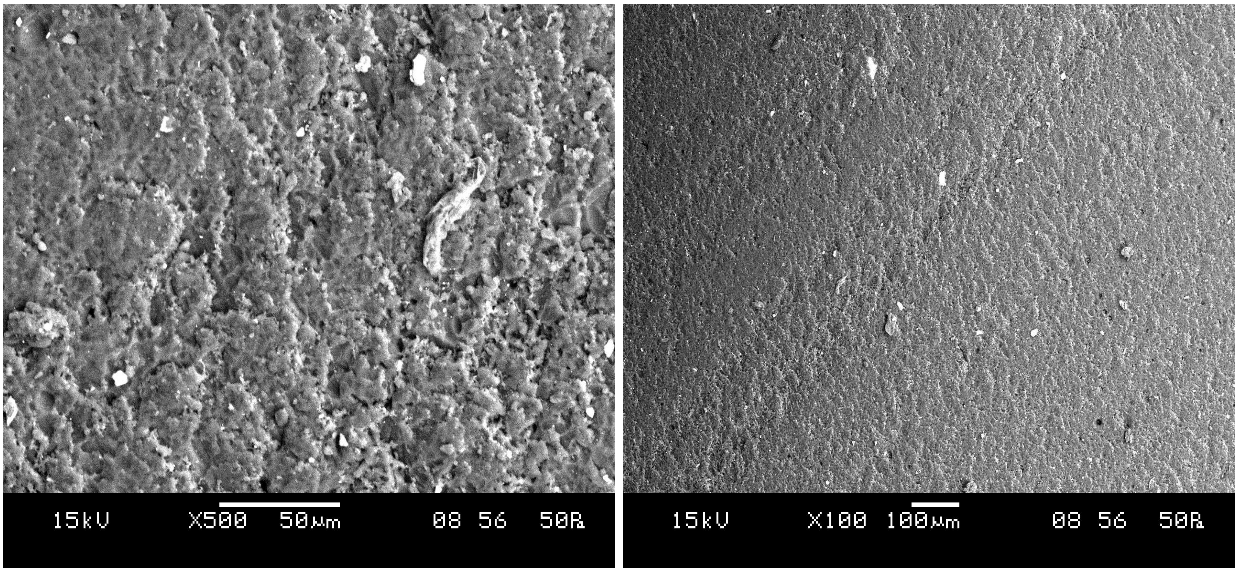

FIGURE 4.23

The worn surface of the composite under Abrasive 420, Normal Load 15N, Sliding Velocity 0.718 m/S, Coir Fiber 20% after 900 seconds.

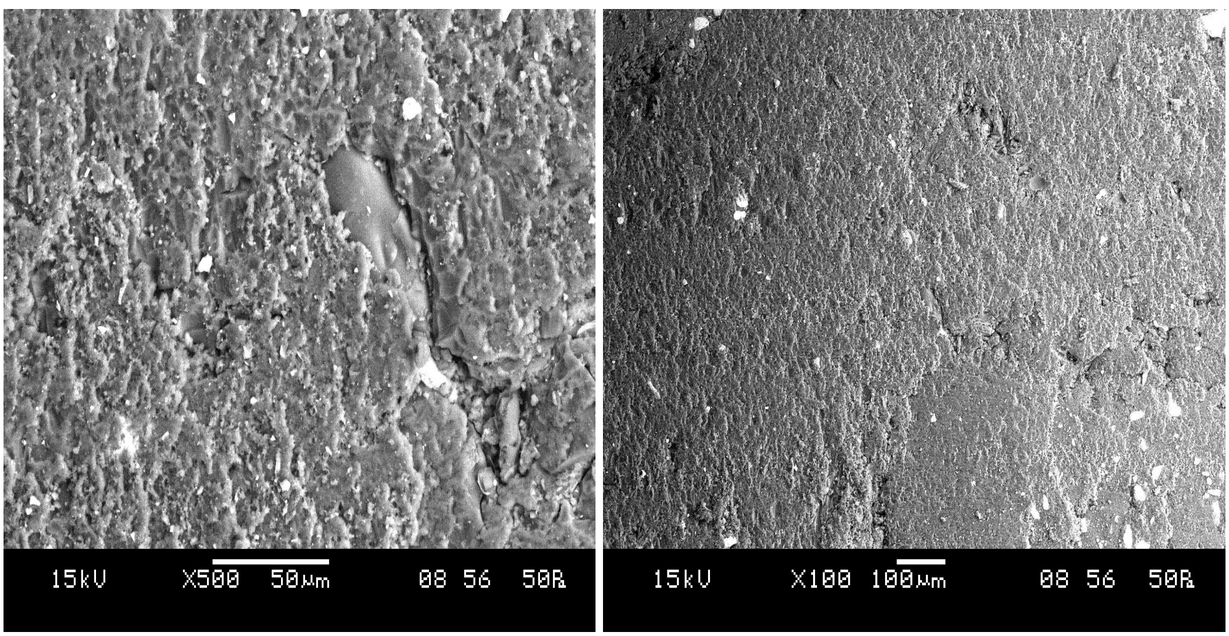

FIGURE 4.24

The worn surface of the composite under Abrasive 420, Normal Load 15N, Sliding Velocity 0.718 m/S, Coir Fiber 30% after 900 seconds.

Effects of abrasive grit size on the morphology of the worn surfaces are shown in figure 4.22 to 4.24. From these it is found that deeper cracks are formed along the sliding direction which is more prominent for the composite with 10% reinforcement. With increase in reinforcement content the material removal is less may be due to distribution of force components in different directions, which is evidenced from smoother grooves on the surface.

4.6 DIELECTRIC BEHAVIOUR

The dielectric behaviour of the fabricated composites were studied by the capacitance measurement method. The samples were cut into thin slices & their surfaces were polished. Then graphite coating is given on thier surfaces to make surface conducting.

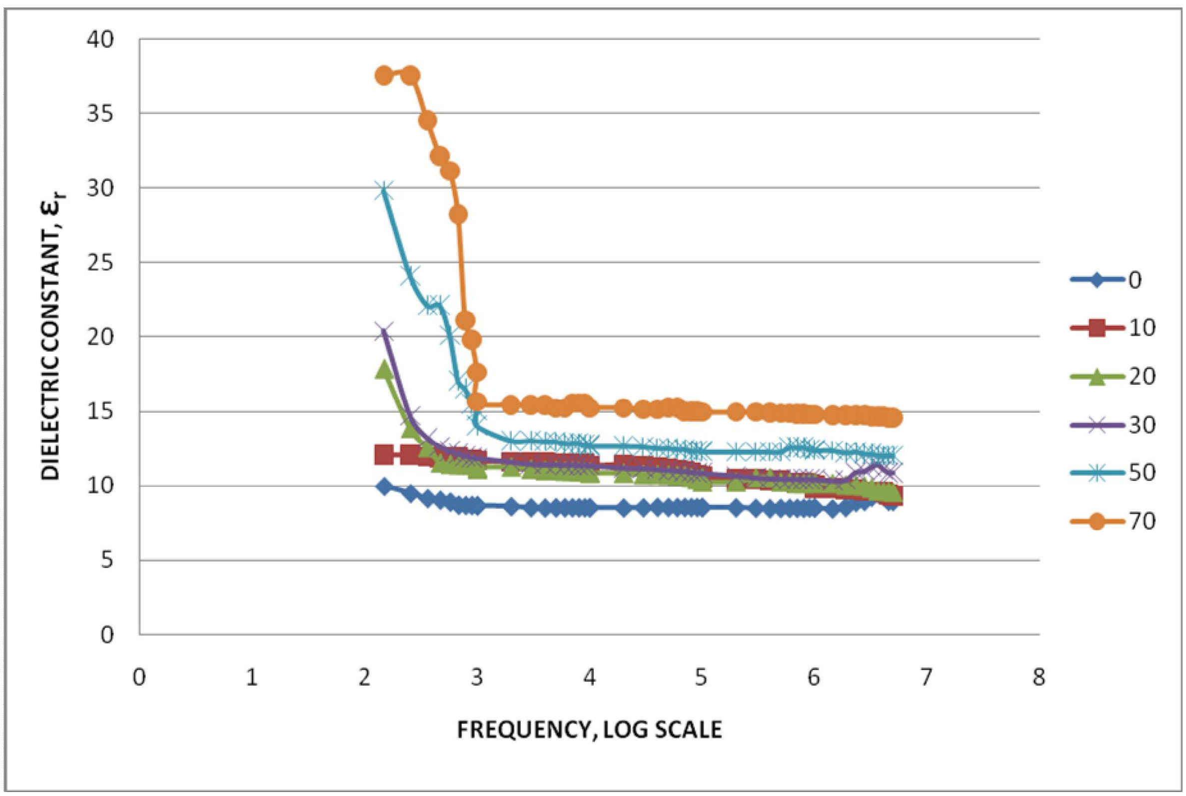

FIGURE 4.25

Variation of dielectric constant with frequency for 0%, 10%, 20%, 30%, 50% and 70% reinforcement at 25^{0}C.

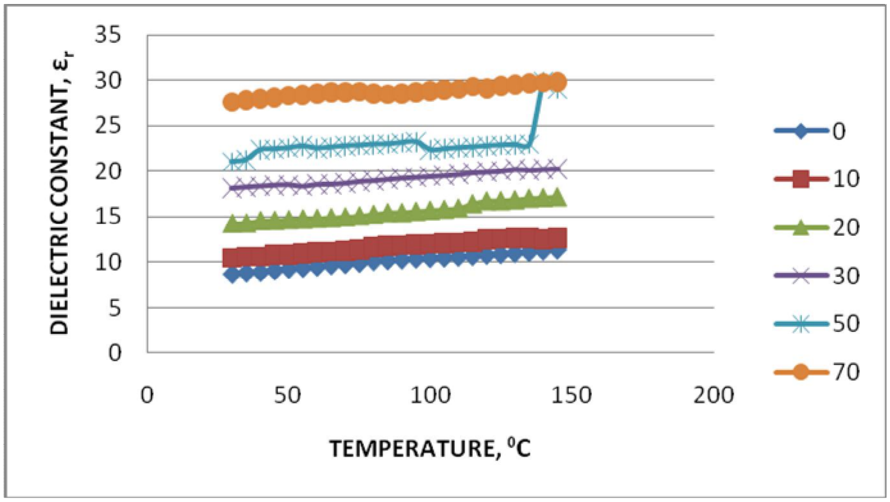

FIGURE 4.26

Variation of dielectric constant with temperature with a frequency 3000 Hz; for 0%,10%,20%,30%,50% and 70% reinforcement.

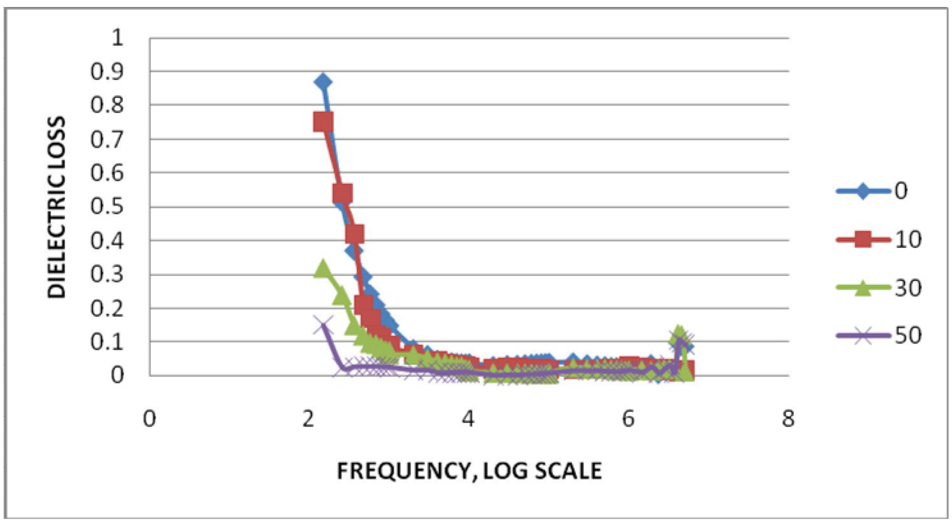

FIGURE 4.27

Variation of dielectric loss with frequency for 0%,10%,30% and 50% reinforcement.

From the figure 4.25 to 4.27 it is found that with increase in reinforcement content dielectric constant shows a higher value at initial stage which gradually decrease and get a stabilizing trend with increase in frequency. With increase in temperature the dielectric constant of the composite shows slightly increasing trend and is higher with higher reinforcement content. However, the dielectric loss takes of a lowering trend and gets stabilized at higher frequency (beyond 3000 Hz). This effect of lowering dielectric loss is suitable for some specific electronic application. These effects are may be due to the fact that the coir fiber contains air gap between inter-vascular regions. So, increase in amount of reinforcement decreases the dielectric loss.

CHAPTER 5
CONCLUSIONS

The conclusions drawn from the conducted investigations are as follows.

1. Coir fiber reinforced polyester composites can be fabricated easily with different weight percent of reinforcement.

2. With increase in reinforcement content the density of the composite decreases.

3. As the result of increment in reinforcement content the hardness of the composite increases slightly.

4. The void fraction of the composite increases slightly with increase in reinforcement content, which might be due to the presence of pores/cavities at inter-fibril spaces.

5. The wear rate increases with increase in the amount of applied load due to the increase in frictional force at the interface.

6. As sliding velocity increases the wear rate is found to increase.

7. With increase in abrasive particle size the wear rate increases due to deeper surface ploughing/penetration causing higher amount of material loss.

8. The most important result is found that with increase in the reinforcement content the wear rate decreases due to distribution of force components in different directions, which is evidenced from smoother grooves on the surface.

9. With increase in frequency the dielectric constant of the composite decreases.

10. As temperature rises the dielectric constant of the composite increases steadily.

11. Dielectric loss associated with the composite decreases with increase in frequency.

12. As the reinforcement content increases the dielectric constant also increases.

SCOPE FOR FUTURE WORK

- Mechanical properties like three point bend test, Charpy impact test are to be conducted for evaluating the mechanical properties of the composites.
- Pre-treatment of the coir fiber before addition to the matrix is to be done and its effect is to be determined.
- Different types of polymer matrices can be tried.

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